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Our goal in this research was to further understand the cognitive mechanism of suppression. In our previous work (supported by AFOSR-89-0305), we found that less-skilled comprehenders are less efficient in suppressing inappropriate, irrelevant, or should-be-ignored information. For instance, less-skilled comprehenders are less efficient in suppressing the inappropriate meanings of ambiguous words (e.g., the playing card meaning of *spade* when they read the sentence *He dug with the spade).* Less-skilled comprehenders are also less efficient in suppressing the incorrect forms of homophones (e.g., the concept of *patients* when they read the sentence, *He had a lot of patience.)* Less-skilled comprehenders are less efficient in ignoring pictures while reading superimposed words, and they are less efficient in ignoring superimposed words while looking at pictures. Furthermore, less-skilled comprehenders' inefficiency in suppressing irrelevant, inappropriate, or to-be-ignored information is not restricted to the language domain: Rather, less-skilled comprehenders are less efficient in suppressing typical-but-absent members of scenic arrays (e.g., a *tractor* in an array of objects typically found in a farm scene). We suggest that less-skilled comprehenders have less efficient suppression mechanisms. In the research we conducted while supported by AFOSR-91-0323, we discovered that the mechanism of suppression is under comprehenders' strategic control, and we discovered that the left cerebral hemisphere appears to be specialized for suppressing ambiguous words.

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FINAL TECHNICAL REPORT

LABORATORY INVESTIGATIONS OF THE COGNITIVE MECHANISM OF SUPPRESSION

COLLABORATIVE RESEARCH IN COGNITIVE PSYCHOLOGY AT THE AIR FORCE HUMAN RESOURCES LABORATORY

DR. MORTON A. GERNSBACHER
DEPARTMENT OF PSYCHOLOGY
UNIVERSITY OF OREGON
EUGENE, OR 97403-1227

CURRENTLY AT

DEPARTMENT OF PSYCHOLOGY
UNIVERSITY OF WISCONSIN-MADISON
1202 W. JOHNSON STREET.
MADISON, WI 53562

March 15, 1993

Prepared for:

John Tangney
AFOSR/NL
Building 410
Bolling AFB DC 20332-6448

A. RESEARCH GOAL

Our goal in this research was to further understand the cognitive mechanisms underlying adult comprehension skill. We envision comprehension skill as drawing on general cognitive processes and mechanisms. The same mechanisms should be involved in nonlinguistic tasks, too. A simple framework that identifies a few of these processes and mechanisms is called the Structure Building Framework (Gernsbacher, 1990; 1991).

According to the Structure Building Framework, the goal of comprehension is to build a cohesive, mental representation or "structure." The first process involved in building this structure is laying a foundation. The next process involves developing the structure by mapping on incoming information when that information coheres or relates to previous information. However, if the incoming information is less coherent or related, comprehenders employ a different process: They shift to initiate a new substructure. Thus, most representations comprise several branching substructures.

The building blocks of these mental structures are memory nodes, which are activated by incoming stimuli. Their initial activation forms the foundation of mental structures. Subsequent information is often mapped onto a developing structure because the more coherent the incoming information is with the previous information, the more likely it is to activate the same or connected memory nodes. But the less coherent the incoming information is, the less likely it is to activate the same or connected memory nodes. In this case, the incoming information might activate a different set of nodes, and the activation of this other set of nodes forms the foundation for a new substructure.

In addition, once memory nodes are activated, they can enhance (boost) or suppress (dampen) other nodes' activation. In other words, two mechanisms control the memory nodes' level of activation: enhancement and suppression. Presumably, memory nodes are enhanced when the information they represent is necessary for further structure building, and they are suppressed when their information is no longer as necessary.

In our previous work (supported by AFOSR-89-0305), which will be described in section C of this report, we found a rather provocative distinction between more-skilled and less-skilled comprehenders: Less-skilled comprehenders are less efficient in suppressing inappropriate, irrelevant, or should-be-ignored information. For instance, less-skilled comprehenders are less efficient in suppressing the inappropriate meanings of ambiguous words (e.g., the playing card meaning of *spade* when they read the sentence *He dug with the spade).* Less-skilled comprehenders are also less efficient in suppressing the incorrect forms of homophones (e.g., the concept of *patients* when they read the sentence, *He had a lot of patience.)* Less-skilled comprehenders are less efficient in ignoring pictures while reading superimposed words, and they are less efficient in ignoring superimposed words while looking at pictures. Furthermore, less-skilled comprehenders' inefficiency in suppressing irrelevant, inappropriate, or to-be-ignored information is not restricted to the language domain: Rather, less-skilled are less efficient in suppressing typical-but-absent members of scenic arrays (e.g., a *tractor* in an array of objects typically found in a farm scene).

We have suggested less-skilled comprehenders have less efficient suppression mechanisms. The research we conducted while supported by AFOSR-91-0323 further investigated the mechanisms of suppression and enhancement. In particular, we investigated whether they are under comprehenders' strategic control, and we began to investigate their neural bases.

B. BACKGROUND

The research we conducted while supported by AFOSR-91-0323 followed directly from the research we conducted while supported by AFOSR-89-0305. Both contracts were issued as part of the Collaborative Research in Cognitive Psychology program. We are very grateful to our AFHRL hosts and the AFOSR collaborative program.

The starting point for both projects was the following finding: Less-skilled comprehenders are less able to reject the inappropriate meanings of ambiguous words. For instance, immediately after both more-skilled and less-skilled adult comprehenders read the word *spade*, both the playing card meaning and the garden tool meaning are momentarily activated. This occurs even when one meaning is strongly implied — for instance, even when the garden tool, not the playing card, meaning of spade is implied as in the sentence,

(1) He dug with the **spade**.

Successful comprehension involves suppressing these contextually inappropriate meanings. Perhaps less-skilled comprehenders are less able to suppress contextually inappropriate meanings.

In Gernsbacher, Varner, and Faust (1990), we tested this hypothesis in the following way. We selected two samples of more- versus less-skilled comprehenders from the extreme thirds of a distribution of 270 University of Oregon students whom we had tested on the Multi-Media Comprehension Battery. When these subjects returned to the lab, they did the following: They read short sentences; after each sentence, they saw a test word. Their task was to verify whether the test word fit the meaning of the sentence they just read. On 80 trials, the test word did indeed fit the sentence, but we were more interested in the 80 trials in which the test word did **not** fit the sentence.

On half of those trials, the last word of the sentence was an ambiguous word, for example,

(2) He dug with the **spade**.

The test word on these trials was a meaning of the ambiguous word that was inappropriate to the context, for example, *ACE*. We measured how long subjects took to reject a test word like *ACE* after reading a sentence like (2). And we compared that latency with how long subjects took to reject *ACE* after reading the same sentence but with the last word replaced by a unambiguous word, for example,

(3) He dug with the **shovel**.

This comparison showed us how activated the inappropriate meaning of the ambiguous word was; the more time subjects took to reject *ACE* after the *spade*- versus the *shovel*-sentence, the more activated the inappropriate meaning must have been.

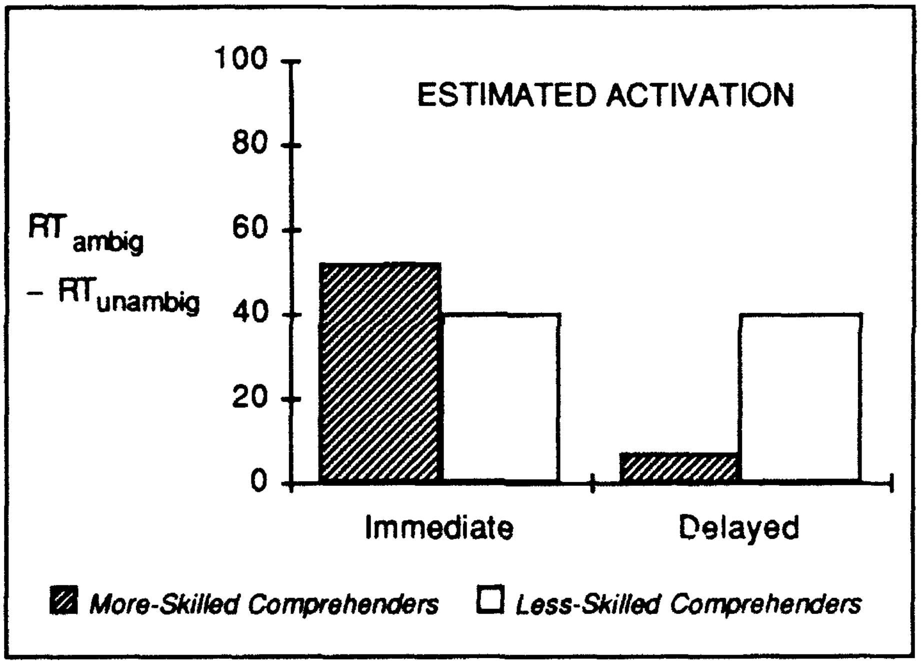
We presented the test words at two intervals: immediately (100 ms) after subjects finished reading each sentence, and after a 850 ms delay. We predicted that at the Immediate interval, both the more- and less-skilled comprehenders would take longer to reject test words after ambiguous than unambiguous words. For example, both groups would take longer to reject *ACE* after reading the *spade* sentence than after reading the *shovel* sentence. This prediction was based on the vast literature demonstrating that immediately after ambiguous words are read, contextually inappropriate meanings are often activated. We particularly expected the inappropriate meanings to be activated because our task required comprehenders to focus their attention on a subsequent word and try to integrate that word into the previous context (Glucksberg, Kreuz, & Rho, 1986; van Petten & Kutas, 1987).

Our novel predictions concerned what would happen after the Delayed interval. We predicted that by that point the more-skilled comprehenders would not take longer to reject test words following ambiguous words. This is because more-skilled comprehenders should be able to successfully suppress the inappropriate meanings. We made a different prediction for our less-skilled comprehenders. If less-skilled comprehenders are plagued by less-efficient suppression mechanisms, then even after the Delayed interval, the inappropriate meanings should still be activated.

Figure 1 (on the next page) displays our 64 subjects' data. We estimated activation by subtracting subjects' latencies to reject test words like *ACE* after reading ambiguous words like *spade* from their latencies to reject test words like *ACE* after reading unambiguous words like *shovel.* The more-skilled comprehenders are represented by hashed lines, and the less-skilled comprehenders are represented by unfilled bars.

First, examine what happened at the Immediate test interval. As Figure 1 illustrates, immediately after both the more- and less-skilled comprehenders read the ambiguous words, the inappropriate meanings were highly activated. Now, examine what happened after the Delayed interval. As Figure 1 illustrates, 850 ms after the more-skilled comprehenders read the ambiguous words, the inappropriate meanings were no longer reliably activated; by this time, the more-skilled comprehenders had successfully suppressed them. But the less-skilled comprehenders were less fortunate: As Figure 1 illustrates, even after the delayed interval, the inappropriate meanings were still highly activated. In fact, they were as highly activated following the delay as they were immediately. So, almost a second after the less-skilled comprehenders read the ambiguous words, they were unable to suppress the inappropriate meanings. These results support the hypothesis that less-skilled comprehenders are plagued by less rapid (and therefore less efficient) suppression mechanisms.

FIGURE 1



C. RESULTS OF RESEARCH CONDUCTED UNDER AFOSR 89-0306

The ability to suppress irrelevant information is undoubtedly a crucial component of comprehension. In many situations, irrelevant or inappropriate information is automatically activated, unconsciously retrieved, or naturally perceived. However, for successful comprehension, irrelevant or inappropriate information must not be allowed to affect ongoing processes. Thus, we viewed further exploring and documenting less-skilled comprehenders' less efficient suppression as a critical step toward understanding individual differences in comprehension skill, as well as general cognitive processing.

In our earlier work (Gernsbacher et al., 1990), we found that less-skilled comprehenders were less efficient in suppressing the inappropriate meanings of ambiguous words. However, to comfortably assume that this inability derives from less efficient suppression mechanisms, we needed to generalize the finding. First, we needed to generalize the finding within the linguistic domain. We wondered whether less-skilled comprehenders are also less efficient in suppressing information that is automatically activated by other linguistic sources? For instance, are they less efficient in suppressing lexical forms that are automatically activated by phonology?

We also needed to generalize our finding outside the linguistic domain. For instance, are less-skilled comprehenders less efficient in suppressing information that is automatically activated during the comprehension of nonverbal scenes? And, are less-skilled comprehenders less efficient at suppressing information across modalities, for example, suppressing linguistic information activated by nonlinguistic stimuli or nonlinguistic information activated by linguistic stimuli?

The research we conducted while supported by AFOSR 89-0306 also investigated an alternative explanation to our previous findings. Perhaps less-skilled comprehenders have difficulty suppressing inappropriate information — not because they have less-efficient suppression mechanisms — but because they less fully appreciate what is contextually appropriate. Two experiments ruled out this counter-explanation.

To summarize, the research we conducted we conducted while supported by AFOSR 89-0306 answered five questions. To answer these questions, we conducted five experiments. Each experiment was based on a different, very well established finding in the cognitive psychology literature. We purposely based our experiments on well established findings so that we could anticipate what "normative" data would look like; we used those expectations to evaluate our less- versus more-skilled comprehenders' data.

Our five research questions were (1) Are less-skilled comprehenders less efficient at suppressing the incorrect forms of homophones? (2) Are less-skilled comprehenders less efficient at suppressing typical-but-absent members of scenic arrays? (3) Are less-skilled comprehenders less efficient at suppressing information across modalities? (4) Are less-skilled comprehenders less able to appreciate the contextually appropriate meaning of an ambiguous word? And (5) are less-skilled comprehenders less efficient at enhancing appropriate members of a scene-oriented array of objects?

In what follows, we present the results of this previous research. A scholarly article presenting these results was published in the journal, *Journal of Experimental Psychology: Learning, Memory & Cognition* (Gernsbacher & Faust, 1991a). We also briefly summarized these results in a chapter prepared for the volume *Comprehending word and sentence* (Gernsbacher & Faust, 1991b).

Are less-skilled comprehenders less efficient at suppressing the incorrect forms of homophones?

Reading a string of letters activates an array of information. Virtually always reading a letter string activates orthographic information — information about the individual letters in the string and their relative position to one another. Often, reading a letter string activates semantic information, lexical information, and phonological information. In fact, semantic, lexical, and phonological information is often activated even when the string does not compose an English word (Coltheart, Davelaar, Jonasson, & Besner, 1977; Rosson, 1985).

Automatic activation of phonological information was the focus of our next experiment. By automatic activation of phonological information I mean the phenomenon in which reading the letter string *rows* activates the phonological sequence */roz/*. In fact, reading *rows* can activate */roz/*, which can activate *rose*. In other words, reading a homophone *(rows)* can activate a phonological sequence *(/roz/)*, which can then activate another form of the homophone *(rose)*. How do we know that a letter string often activates phonological information, which in turn activates other forms of homophones? Consider the following finding: Comprehenders have difficulty quickly rejecting the word *rows* as not being an exemplar of the category *FLOWER* (van Orden, 1987; van Orden, Johnston, & Hale, 1988).

But to successfully comprehend a written passage, these incorrect forms cannot remain activated. According to the Structure Building Framework, comprehension involves the mechanism of suppression. The same structure building mechanism that suppresses the inappropriate meanings of ambiguous words, could also suppress the incorrect forms of homophones. If this is the same mechanism, and if this general suppression mechanism is less efficient in less-skilled comprehenders, then less-skilled comprehenders should also less-efficiently suppress the incorrect forms of homophones.

Related evidence already supports this prediction. Consider the sentence:

(6) She **blue** up the balloon.

Six-year olds are more likely to accept that sentence than are 10-year olds — even when they clearly know the difference between *blue* and *blew* (Doctor & Coltheart, 1980) see also (Coltheart, Laxon, Rickard, & Elton, 1988). If we assume that 6-year olds are less skilled than 10-year olds at comprehension, this finding suggests that less-skilled comprehenders are less able to suppress the incorrect forms of homophones that are often automatically activated.

While supported by AFOSR 89-0306, we tested this hypothesis more directly, with adult subjects whom we knew differed in their General Comprehension Skill. Our subjects were US Air Force recruits who were drawn from a sample of 455 subjects whom we tested with the Multi-Media Comprehension Battery. We drew 48 subjects from the top third of the distribution (those who scored the highest) and 48 subjects from the bottom third of the distribution (those who scored the lowest).

When these more- versus less-skilled comprehenders returned to the lab, they performed a laboratory task similar to the task we used in our previous research. They read short sentences, and following each sentence, they saw a test word. The subjects verified whether the test word fit the meaning of the sentence they just read. On 80 trials, the test word did indeed fit the sentence's meaning, but on 80 trials it did not. We were interested in those trials in which the test word did **not** fit the meaning.

On half of those trials, the last word of the sentence was one form of a homophone, for example,

(7) He had lots of **patients**.

On these trials, the test word was related to the homophone's other form, for example, the test word *CALM* is related to *patience*. We compared how long subjects took to reject *CALM* after reading sentence (7) with how long they took to reject *CALM* after reading the same sentence with the last word replaced by a nonhomophone, for example,

(8) He had lots of **students**.

This comparison showed us how activated the incorrect form was; the more time subjects took to reject *CALM* after the *patients*- versus *students*-sentence, the more activated the *patients* form of the homophone must have been.[5]

We presented the test words at two intervals: Immediately (100 ms) after subjects finished reading each sentence, and after a one-second Delay. We predicted that at the Immediate interval, both the more- and less-skilled comprehenders would take longer to reject test words following homophones than nonhomophones. For example, both groups would take longer to reject *CALM* after reading the *patients* sentence than after reading the *students* sentence. This result would corroborate the results of van Orden (1987; van Orden et al., 1988). This result would also demonstrate that comprehenders of both skill levels often activate phonological information during reading.

Our novel predictions concerned what would happen after the Delayed interval. We predicted that after the one-second delay, the more-skilled comprehenders would not take longer to reject test words following homophones versus nonhomophones; more-skilled comprehenders should be able to successfully suppress incorrect forms. We made a different prediction for our less-skilled comprehenders. If less-skilled comprehenders are characterized by less-efficient suppression mechanisms, then even after the one-second delay, the incorrect forms of the homophones should still be highly activated.

FIGURE 2

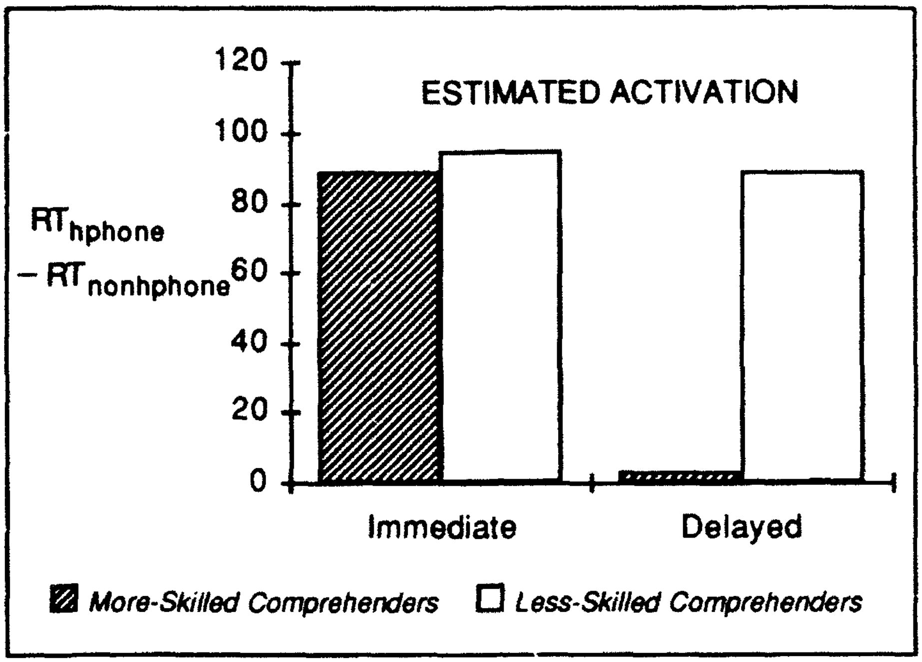


Figure 2 illustrates our 96 subjects' data. We estimated activation by subtracting subjects' latencies to reject test words like *CALM* after reading nonhomophones like *students* from their latencies to reject test words like *CALM* after reading homophones like *patients*. First examine what happened at the Immediate test interval. As Figure 2 illustrates, immediately after both the more- and less-skilled comprehenders read the homophones, the inappropriate forms were highly activated; in fact, they were almost equally activated for the more- versus less-skilled comprehenders. So, 100 ms after comprehenders of both skill levels read homophones, other forms are often activated.

Now examine what happened after the one-second Delayed interval. As Figure 2 illustrates, one second after the more-skilled comprehenders read the homophones, the incorrect forms were no longer reliably activated; the more-skilled comprehenders had successfully suppressed them. But as Figure 2 also illustrates, the less-skilled comprehenders were less fortunate: Even after the Delayed interval, the incorrect forms were still highly activated; in fact, they were as activated after one second as they were immediately. So, a second after the less-skilled comprehenders read the homophones, they were unable to suppress the incorrect forms. These data support the hypothesis that less-skilled comprehenders are plagued by less-efficient suppression mechanisms.

Are less-skilled comprehenders less efficient at suppressing typical-but-absent members of scenes?

According to the Structure Building Framework, many of the cognitive processes and mechanisms involved in comprehending language are involved in comprehending nonlinguistic stimuli, for instance, naturalistic scenes. Other researchers also consider scene perception as "comprehension" (Biederman, 1981; Friedman, 1979; Mandler & Johnson, 1976).

The mechanisms of enhancement and suppression are critical to scene comprehension. Indeed, Biederman writes about the difficulty in "suppressing the interpretations of visual arrays that comprise scenes" (Biederman, Bickle, Teitelbaum, & Klatsky, 1988), p. 456). This difficulty is manifested in the following phenomenon: After briefly viewing a scene, subjects are more likely to incorrectly report that an object was present if that object is typically found in that type scene. For instance, subjects are more likely to incorrectly report that a tractor was present in a farm scene than a kitchen scene, and they are more likely to incorrectly report that a kettle was present in a kitchen scene than a farm scene (Biederman, Glass, & Stacy, 1973; Biederman, Mezzanotte, & Rabinowitz, 1982; Biederman, Teitelbaum, & Mezzanotte, 1983; Palmer, 1975).

To successfully comprehend a scene, observers must suppress these typical-but-absent objects, just as readers and listeners must suppress the inappropriate meanings of ambiguous words and the incorrect forms of homophones. The same structure building mechanism that suppresses the activation of inappropriate linguistic information could suppress the activation of inappropriate nonlinguistic information. If this is the same mechanism, and if this general suppression mechanism is less efficient in less-skilled comprehenders, then less-skilled comprehenders should also be less efficient in suppressing the activation of typical-but-absent objects when viewing scenes.

We tested this hypothesis using Biederman et al.'s (1988) stimuli. Biederman et al. (1988) replicated the phenomenon in which subjects incorrectly report that an object is present in a scene when the object is typical of that scene (for instance, subjects incorrectly report that a tractor was present in a farm scene). But instead of briefly viewing actual scenes, the subjects in Biederman et al.'s (1988) experiments viewed clock-face arrangements of objects, as illustrated in Figure 3 (on the next page). For instance, the top left panel of Figure 3 illustrates a clock-face arrangement of six objects normally found in a farm scene: *a barn, a pig, a pitchfork, a farmer, a rooster, and an ear of corn*. I shall refer to these clock-face arrangements as scenic arrays.

We presented all of Biederman et al.'s (1988) scenic arrays that comprised three, four, five, and six objects. However, we slightly modified Biederman et al.'s task so that it would better parallel our linguistic tasks. In our experiment, subjects first viewed a scenic array; then, they saw the name of a test object. Their task was to verify whether the named test object had been present in the array they just viewed. On 80 trials, the test object had been present, but in 80 it had not. In this experiment, we were interested in the trials in which the test object had **not** been present.

On half of those trials, the objects in the array were typical of a particular scene, for instance, objects that typically occur in a farm scene, as illustrated in top left panel of Figure 3. On these trials, the test object was something that also typically occurs in this type scene, but it had not been present in the scenic array that the subjects just viewed. For instance, a *TRACTOR* typically occurs in a farm scene, but no *TRACTOR* occurs in the scenic array illustrated in the top panel of Figure 3.

We compared how long subjects took to reject *TRACTOR* after viewing the farm array with how long they took to reject *TRACTOR* after viewing another scenic array, for instance, objects belonging to a kitchen scene, as illustrated in the bottom panel of Figure 3. This comparison showed us how activated the typical-but-absent object was: The longer subjects took to reject *TRACTOR* after viewing the typical *(farm)* array versus the atypical *(kitchen)* array, the more activated the typical-but-absent object must have been.

We presented the names of the test objects at two intervals: Immediately (50 ms) after subjects viewed each array, and after a one-second Delay. We predicted that at the Immediate interval, both the more- and less-skilled comprehenders would take longer to reject test objects following typical than atypical scenic arrays. For example, both groups would take longer to reject *TRACTOR* after viewing the farm array than after viewing the kitchen array. This result would corroborate the results of Biederman and his colleagues. This result would also demonstrate that comprehenders of both skill levels immediately activate typical-but-absent object when viewing scenic arrays.

Our novel predictions concerned what would happen after the Delayed interval. We predicted that after the one-second delay, the more-skilled comprehenders would not take longer to reject test objects following typical than atypical arrays. After one second, more-skilled comprehenders should be able to successfully suppress typical-but-absent objects. But we made a different prediction for our less-skilled comprehenders. If less-skilled comprehenders are characterized by less-efficient suppression mechanisms, then even after the one-second delay, the typical-but-absent objects should have still been highly activated.

FIGURE 3

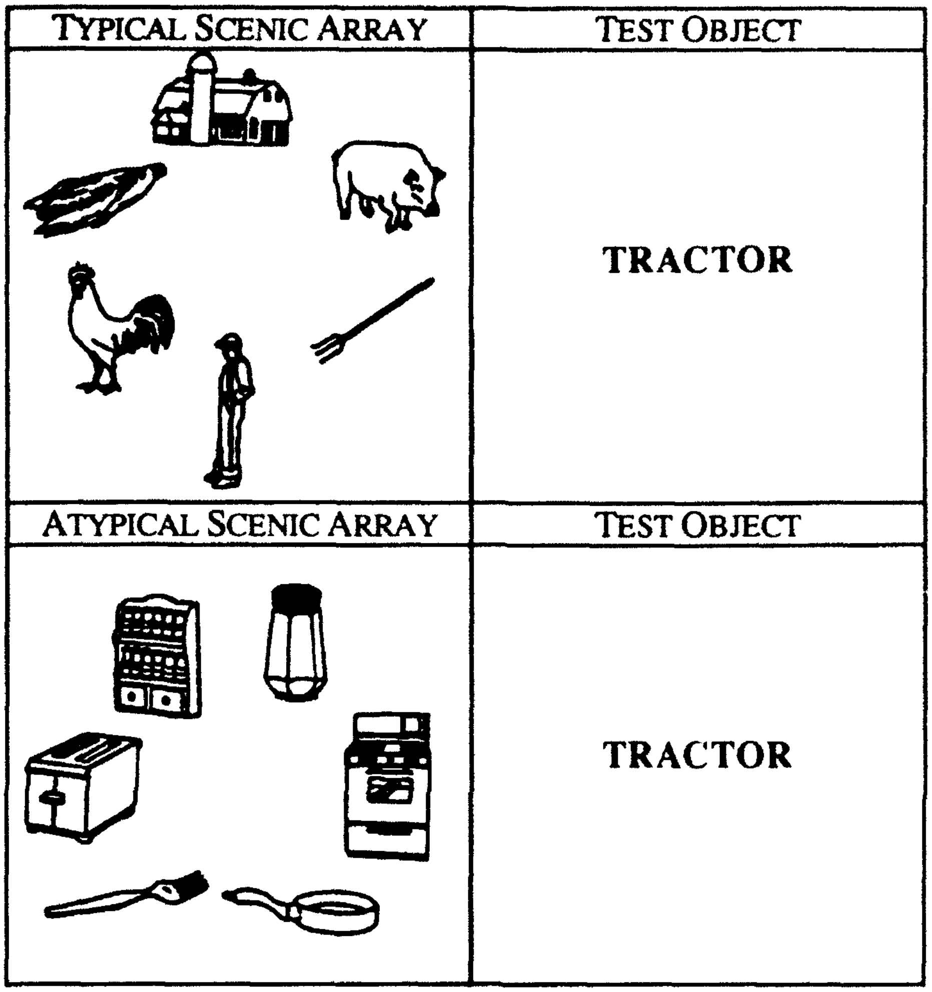
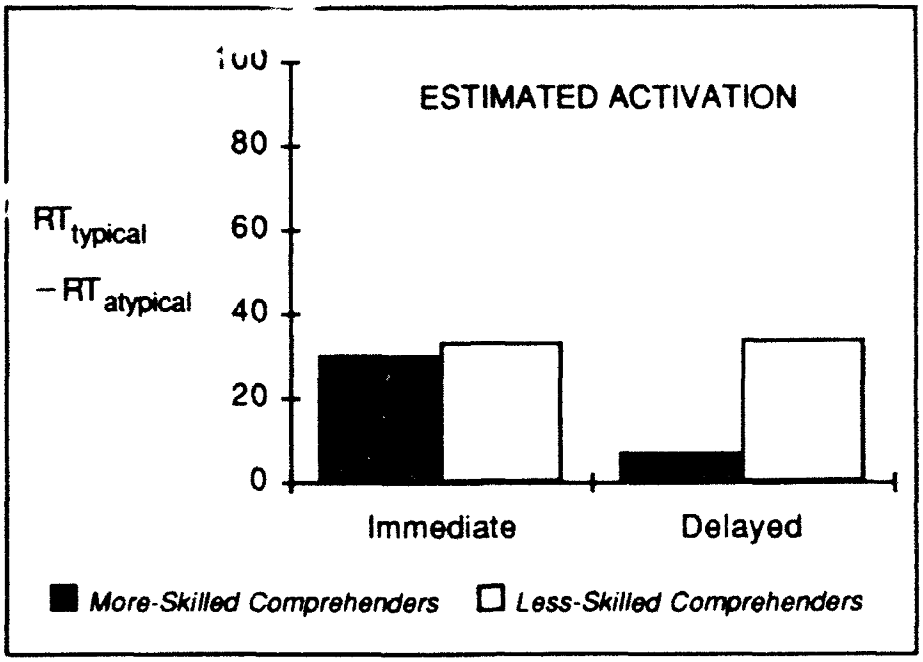


Figure 4 displays our 40 subjects' data. We estimated activation by subtracting subjects' latencies to reject names of test objects like *TRACTOR* after viewing atypical *(kitchen)* arrays from their latencies to test objects like *TRACTOR* after viewing typical *(farm)* arrays. First examine what happened at the Immediate test interval. As Figure 4 illustrates, immediately after both the more- and less-skilled comprehenders viewed the scenic arrays, the typical-but-absent objects were highly activated. In fact, the typical-but-absent objects were about equally activated for the more- versus less-skilled comprehenders.

Now examine what happened after the one-second Delayed interval. As Figure 4 illustrates, one second after the more-skilled comprehenders viewed the scenic arrays, the typical-but-absent objects were no longer reliably activated; the more-skilled comprehenders had successfully suppressed them. But as Figure 4 also illustrates, the less-skilled comprehenders were less fortunate: Even after the Delayed interval, the typical-but-absent objects were highly activated; in fact, they were as activated after the one-second delay as they were immediately. So, even a full second after the less-skilled comprehenders viewed the arrays, they were still unable to suppress the typical-but-absent objects. These data support the hypothesis that less-skilled comprehenders are plagued by less-efficient suppression mechanisms.

FIGURE 4



Are less-skilled comprehenders less efficient at suppressing information across modalities?

To negotiate the environment, we must make sense of stimuli that originate from various modalities. We would be severely handicapped if we were skilled at only reading written words, or only listening to spoken words, or only comprehending graphic displays. Information originates from different modalities, often simultaneously. We read while listening to music, and we drive while carrying on a conversation.

Comprehenders often experience interference across modalities. For instance, it is harder to name a pictured object such as an *ashtray* if a letter string such as *INCH* is written across the picture, as illustrated in the upper left panel of Figure 5. The opposite is also true: It is harder to read a word such as *RIVER* if it is superimposed on a picture, as illustrated in the bottom left panel of Figure 5 (Smith & McGee, 1980).

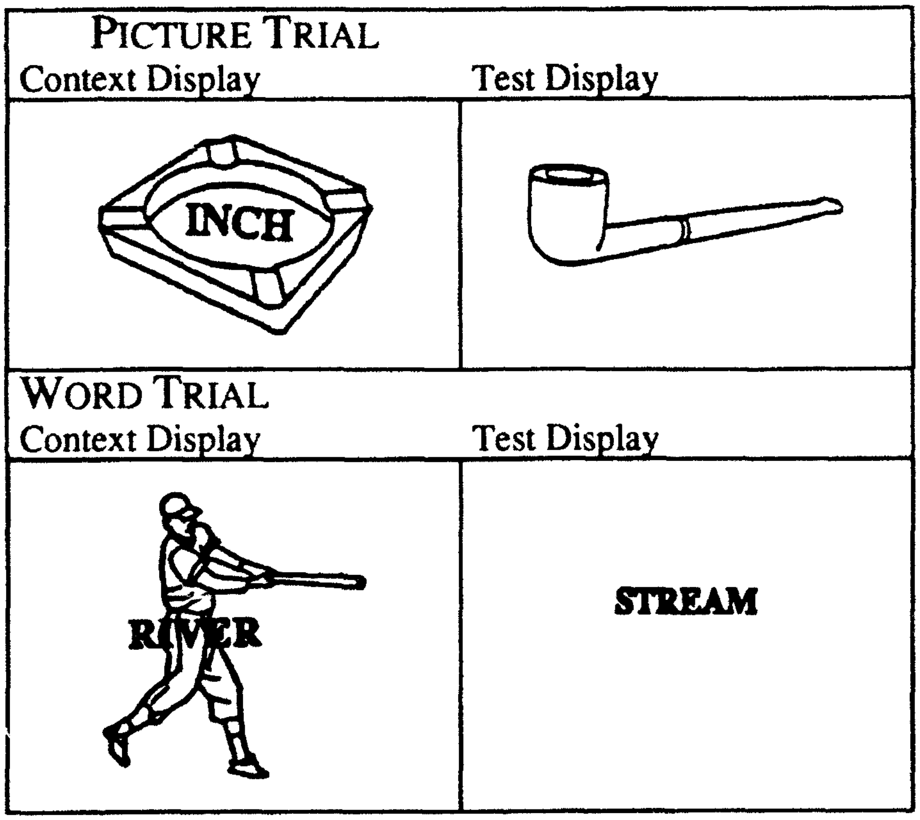
Successful comprehension often requires suppressing information across modalities. The same structure building mechanism that suppresses information within modality, could suppress information across modalities. If this is the same mechanism, and if this general suppression mechanism is less efficient in less-skilled comprehenders, then less-skilled comprehenders should also be less efficient in suppressing information across modalities.

We tested this hypothesis in the following way. We modified Tipper and Driver's (1988) experimental task. In our modification, subjects first viewed a context display. Each context display contained a line-drawn picture of a common object and a familiar word. For example, the top panel in Figure 5 illustrates a picture of an *ashtray* with the word *INCH* written across it. The bottom panel of Figure 5 illustrates the word *RIVER* superimposed on a picture of a *baseball player*. All context displays contained both a picture and a word.

After subjects viewed each context display, they were shown a test display. Each test display contained either another picture or another word. Half the time, the test display contained another picture, and we referred to those trials as Picture trials; half the time, the test display contained another word, and we referred to those trials as Word trials. Subjects were told before each trial whether that trial would be a Picture trial or a Word trial.

The top panel of Figure 5 illustrates a Picture trial. On Picture trials, subjects were told to focus on the picture in the context display and ignore the word. For example, for the Picture trial shown in Figure 5, subjects should have focused on the *ashtray* and ignored the word *INCH*. Following each context display, subjects were shown a test display. On the Picture trials, the test display contained another picture. The subjects' task (on Picture trials) was to verify whether the picture shown in the test display was related to the picture shown in the context display. For the Picture trial shown in Figure 5, subjects should have responded "yes," because the picture shown in the test display, the *pipe*, was related to the picture shown in the context display, the *ashtray*.

FIGURE 5

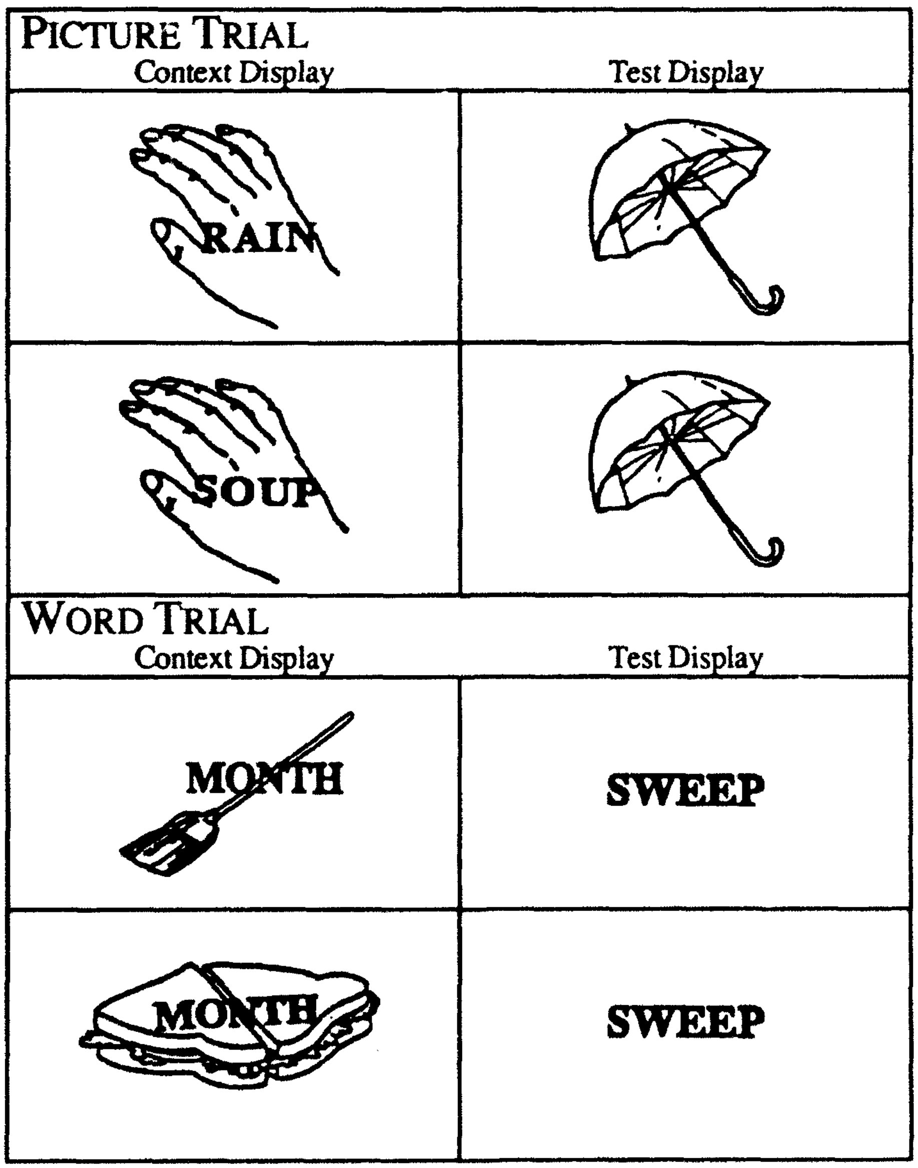


The bottom panel of Figure 5 illustrates a Word trial. On Word trials, subjects were supposed to focus on the word in the context display and ignore the picture. For example, for the Word trial shown in Figure 5, subjects should have focused on the word *RIVER* and ignored the *baseball player*. The test display on Word trials contained another word. The subjects' task was to verify whether the word written in the test display was related to the word written in the context display. For the Word trial shown in Figure 5, subjects should have responded "yes," because the word written in the test display, *STREAM*, was related to the word written in the context display, *RIVER*.

On 40 Picture trials and 40 Word trials, the test display was related to what the subjects were to focus on in the context display, just as they are in Figure 5. However, we were more interested in the 80 trials in which the test display was unrelated to what the subjects were supposed to focus on in the context display. On half of those trials, the test display was unrelated to what the subjects were to focus on in the context display, but it was related to what they were supposed to ignore.

For example, the top panel in Figure 6 illustrates an experimental Picture trial. The context display contains a picture of a *hand* with the superimposed word *RAIN*. Because this is a Picture trial, subjects should have focused on the picture (the *hand)* and ignored the word. The test display is a picture of an *umbrella*. So the test display, the *umbrella*, is unrelated to what the subjects were supposed to focus on in the context display, the *hand;* therefore, the subjects should have responded "no." But the test display is related to what the subjects were supposed to ignore, the word *RAIN*. We measured how long subjects took to reject the test display, the picture of the *umbrella*, after viewing the context display, the picture of the *hand* with the superimposed word *RAIN*. And we compared that with how long subjects took to reject the same test display, the picture of the *umbrella*, after viewing the same context display, the picture of the *hand*, but with another word superimposed, *SOUP*. This comparison showed us how quickly comprehenders could suppress information across modalities.

FIGURE 6



Experimental Word trials worked similarly, as illustrated by the third panel of Figure 6. When reading this context display, subjects should have focused on the word *MONTH* and ignored the surrounding picture of a *broom*. Then, they should have rejected the test display, the word *SWEEP*, because it is unrelated to the word *MONTH*. We measured how long subjects took to reject the word *SWEEP* after reading the word *MONTH* surrounded by the *broom*. And we compared that with how long subjects took to reject *SWEEP* after viewing the same context display with the picture of a *broom* replaced by a picture of a *sandwich* (as illustrated by the bottom panel of Figure 6). This comparison showed us how quickly comprehenders could suppress information across modalities.

As in our other experiments, we presented the test displays at two intervals: Immediately (50 ms) after the context-setting display, and after a one-second Delayed interval. We predicted that at the Immediate interval, both the more- and less-skilled comprehenders would take longer to reject a test display when it was related to the ignored picture or word in the context display. This result would corroborate Tipper and Driver (1988). This result would also demonstrate that both more- and less-skilled comprehenders have immediate difficulty suppressing information across modalities.

Our novel predictions concerned what would happen after the Delayed interval. We predicted that after the one-second delay, the more-skilled comprehenders would not take longer to reject test displays when they were related to the ignored pictures/words. After one second, more-skilled comprehenders should be able to successfully suppress information across modalities. We made a different prediction for our less-skilled comprehenders. If less-skilled comprehenders are characterized by less-efficient suppression mechanisms, then even after the one-second delay, the ignored pictures and words should still be highly activated.

FIGURE 7

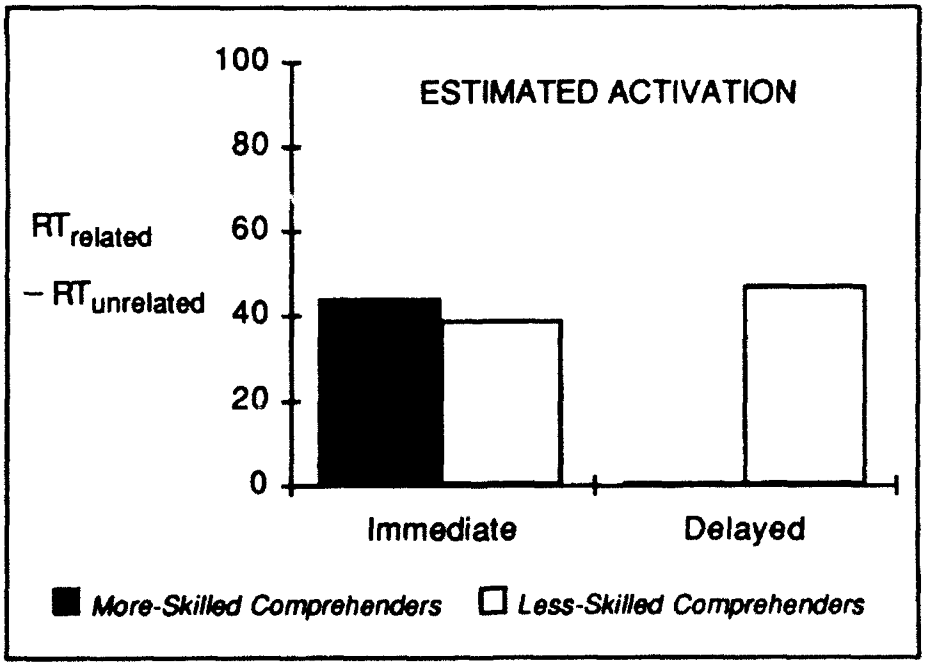


Figure 7 displays our 160 subjects' data. We estimated activation by subtracting subjects' latencies to reject test displays that were unrelated to ignored pictures/words from their latencies to reject test displays that were related to ignored pictures/words.[6] First examine what happened at the Immediate test interval. As Figure 7 illustrates, immediately after both the more- and less-skilled comprehenders saw the context displays, the ignored pictures/words were highly activated; in fact, they were almost equally activated for the more- versus less-skilled comprehenders. So, 50 ms after viewing pictures with superimposed words or reading words surrounded by pictures, comprehenders of both skill levels have difficulty suppressing related pictures or words, even when they are told explicitly to ignore them.

Now, examine what happened after the one-second Delayed interval. As Figure 7 illustrates, one second after the more-skilled comprehenders saw the context displays, the ignored pictures/words were no longer reliably activated; the more-skilled comprehenders had successfully suppressed them. But as Figure 7 also illustrates, the less-skilled comprehenders were less fortunate: Even after the Delayed interval, the ignored pictures/words were still highly activated; in fact, they were as activated after the Delayed interval as they were immediately. So, one second after less-skilled comprehenders view pictures with superimposed words or read words surrounded by pictures, they still have difficulty suppressing the ignored pictures or words. These data support the hypothesis that less-skilled comprehenders are plagued by less-efficient suppression mechanisms.

So, a critical characteristic of less-skilled comprehenders is their inefficiency in suppressing inappropriate or irrelevant information while they are comprehending both linguistic and nonlinguistic information. This in turn could account for their tendency to shift too often, their tendency to build too many substructures, and their poorer access to recently comprehended information.

In the experiments we just described, we found that less-skilled comprehenders were less efficient at rejecting irrelevant or inappropriate information. We suggested that less-skilled comprehenders have less-efficient suppression mechanisms. A counter-explanation is that less-skilled comprehenders have difficulty suppressing inappropriate information — not because they have less-efficient suppression mechanisms — but because they less fully appreciate what is contextually appropriate. Perhaps they have less efficient enhancement mechanisms.

Are less-skilled comprehenders less efficient at enhancing the contextually-appropriate meanings of ambiguous words?

According to the Structure Building Framework, comprehension requires enhancing the activation of memory nodes when those nodes are relevant to the structure being built. So, perhaps less-skilled comprehenders' enhancement mechanisms, not their suppression mechanisms, are at fault. By this logic, less-skilled comprehenders have more difficulty rejecting *ACE* after reading *He dug with the spade* because they less fully appreciate that the context of ***digging** with a spade* implies a garden tool, not a playing card.

This explanation seems unlikely given the repeated finding that less-skilled comprehenders are not less appreciative of predictable sentence contexts — just the opposite: Less-skilled comprehenders often benefit from predictable contexts more than more-skilled comprehenders do. For example, the word *dump* is very predictable in the following context:

> (9) The garbage men had loaded as much as they could onto the truck. They would have to drop off a load at the garbage **dump**.

In contrast, *dump* is less predictable in the following context:

> (10) Albert didn't have the money he needed to buy the part to fix his car. Luckily, he found the part he wanted at the **dump**.

All comprehenders pronounce the word *dump* more rapidly when it occurs in the very predictable context than when it occurs in the less predictable context; in other words, all comprehenders benefit from the predictable contexts. But less-skilled comprehenders benefit even more than more-skilled comprehenders.

We also evaluated this counter-explanation with adult comprehenders and a task similar to those we used in our previous experiments. Subjects read short sentences, and following each sentence, they saw a test word. As in our other experiments, the subjects' task was to verify whether the test word fit the meaning of the sentence they just read. However, in this experiment we were most interested in the 80 trials in which the test word did indeed match the meaning of the sentence (and, therefore, the subjects should have responded "yes").

On half of those trials, the last word of the sentence was an ambiguous word, for example, *spade*, and the verb in the sentence biased one meaning of the ambiguous word, for example,

(11) He **dug with** the spade.

The test word was related to the meaning of the ambiguous word that was biased by the verb, for example, *GARDEN*. In a comparison condition we presented the same sentence, but the biasing verb was replaced with a neutral verb, for example,

(12) He **picked up** the spade.

The *spade* in sentence (12) could be either a garden tool or a playing card.

We measured how rapidly subjects accepted test words after reading sentences with biasing verbs versus neutral verbs.[7] This comparison showed us how fully comprehenders could appreciate the biasing contexts: The faster subjects were to accept *GARDEN* after reading the sentence with the biasing verb phrase ***dug with*** versus the neutral verb phrase ***picked up***, the more fully they appreciated the biasing context.

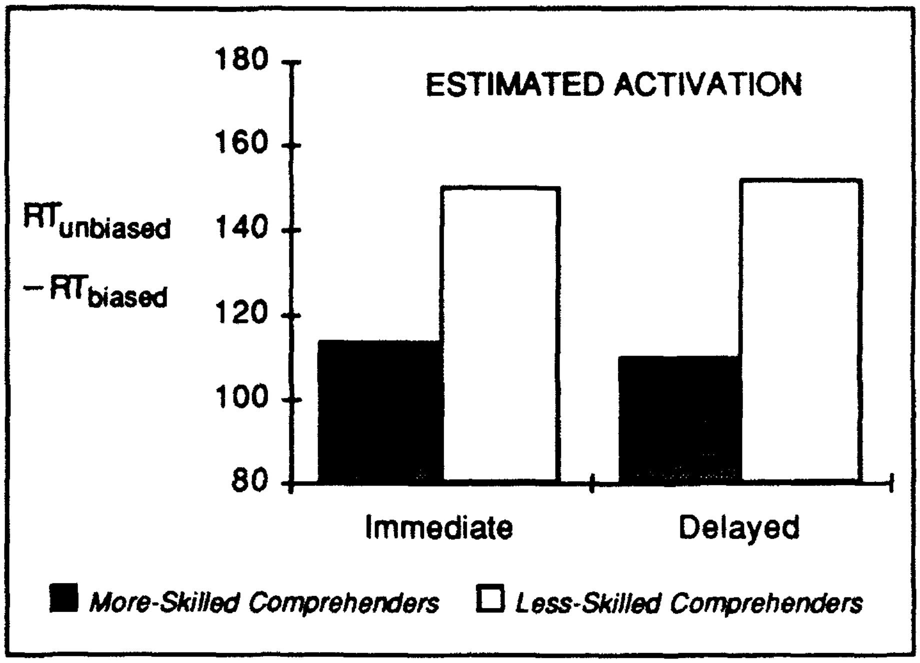
We presented the test words at two intervals: Immediately (100 ms) after subjects finished reading each sentence, and after a one-second Delay. We predicted that both the more- and less-skilled comprehenders would benefit from the biasing contexts; that is, both groups of comprehenders would accept test words more rapidly when the sentences contained biasing as opposed to neutral verbs. However, we were especially interested in whether the less-skilled comprehenders would benefit less than the more-skilled comprehenders.

If less-skilled comprehenders are less efficient at rejecting contextually inappropriate information (as we found in our previous experiments) because they are less appreciative of context, then the less-skilled comprehenders should have benefited less from the biasing contexts. In contrast, if less-skilled comprehenders are less efficient at rejecting inappropriate information because they have less efficient suppression mechanisms, then the less-skilled comprehenders should have benefited just as much from the biasing contexts as the more-skilled comprehenders did. Based on previous literature, we predicted that the less-skilled comprehenders would benefit even more from the biasing contexts than the more-skilled comprehenders did.

Figure 8 displays our 120 subjects' data. We estimated activation by subtracting subjects' latencies to accept test words like *GARDEN* after reading sentences with biasing verbs like ***dug with*** from their latencies to accept *GARDEN* after reading sentences with unbiased verbs like ***picked up***.

As Figure 8 illustrates, at both the Immediate and the Delayed test intervals, the biased verbs led to greater activation, and this occurred for both more- and less-skilled comprehenders. Indeed, as Figure 8 also illustrates, at both test intervals, the less-skilled comprehenders benefited from the biasing verbs more than the more-skilled comprehenders benefited. These data do not support the hypothesis that less-skilled comprehenders are characterized by less-efficient enhancement mechanisms.

FIGURE 8



Are less-skilled comprehenders less efficient at enhancing typical objects in scenes?

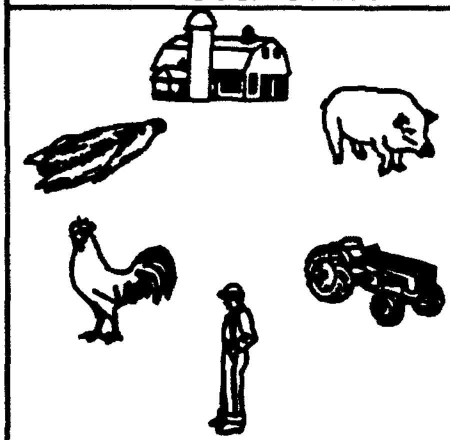
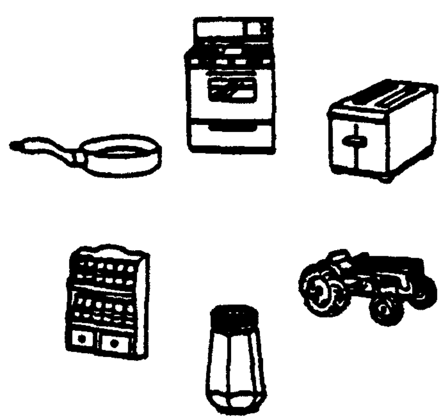
Just as sentence comprehension requires enhancing the contextually appropriate meanings of words, scene comprehension requires enhancing the objects present in the visual array. And, just as less-skilled comprehenders might be less efficient at enhancing the contextually appropriate meanings of words, they might also be less efficient at enhancing the objects present in a visual scene.

We tested this hypothesis in the following way. Subjects first viewed a scenic array of objects, and then they read the name of a test object. For instance, subjects first viewed the scenic array illustrated in the top panel of Figure 9, and then they saw the test object, *TRACTOR*. The subjects' task was to verify whether the test object had been present in the array they just viewed. On 80 trials, the test object had not been present, but on 80 it had. In this experiment, we were interested in the trials in which the test object had been present (and, therefore, the subjects should have responded "yes").

On half of those trials, the other objects in the array were typical of the scene in which the test object typically occurs. For example, the other objects in the array shown in the top panel of Figure 9 typically occur in a farm scene, just as a *tractor* does. In a comparison condition, the other objects were atypical of the scene in which the test object typically occurs. For example, the other objects in the array shown in the bottom panel of Figure 9 do not typically occur in a farm scene.

We compared how rapidly subjects accepted *TRACTOR* after viewing it in an array of typical objects with how rapidly they accepted *TRACTOR* after viewing it in an array of atypical objects. This comparison showed us how fully comprehenders could appreciate the typical contexts: The faster subjects were to accept *TRACTOR* after viewing the array of typical versus atypical objects, the more fully the subjects must have appreciated the context.

FIGURE 9

TYPICAL SCENIC ARRAY	TEST OBJECT
	**TRACTOR**
ATYPICAL SCENIC ARRAY	TEST OBJECT
	**TRACTOR**

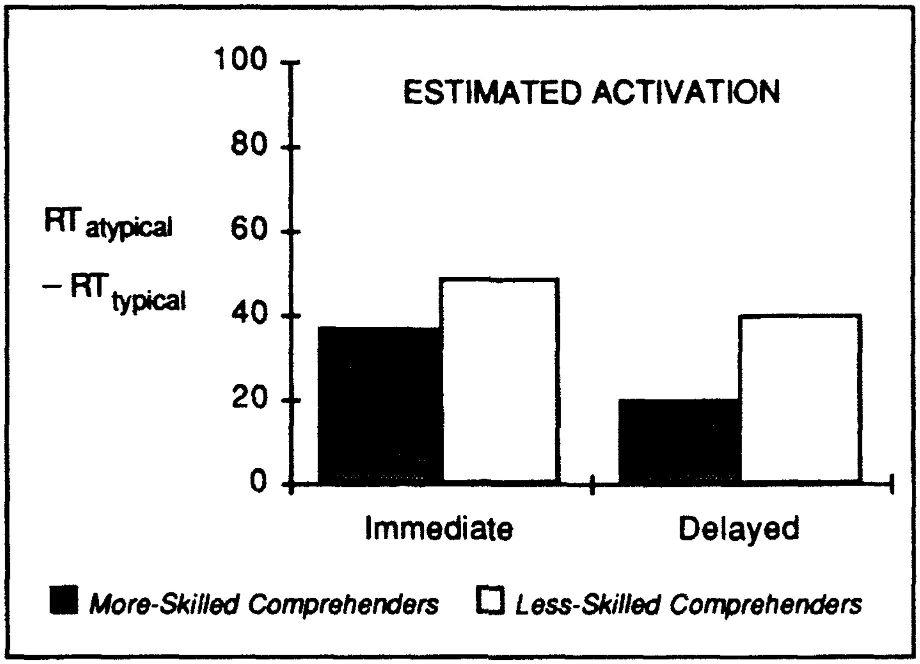
We presented the names of the test objects at two intervals: Immediately (50 ms) after subjects finished viewing each scenic array, and after a one-second Delay. We expected that both the more- and less-skilled comprehenders would benefit from the typical contexts. That is, both groups of comprehenders would accept test objects more rapidly when the arrays contained typical objects as opposed to atypical objects. This result would corroborate Biederman et al. (1988).

However, we were interested in whether the less-skilled comprehenders would benefit less from the typical contexts. If less-skilled comprehenders are less efficient at rejecting contextually inappropriate information (as we found in our previous experiments) because they are less appreciative of context, then they should have benefited less from the typical contexts. In contrast, if less-skilled comprehenders are less efficient at rejecting inappropriate information because they have less efficient suppression mechanisms, then they should have benefited just as much from the typical contexts as the more-skilled comprehenders did.

Figure 10 displays our 40 subjects' data. We estimated activation by subtracting subjects' latencies to accept test objects like *TRACTOR* after viewing a *tractor* in a typical *(farm)* array from their latencies to accept *TRACTOR* after viewing a *tractor* in an atypical *(kitchen)* array.

As Figure 10 illustrates, at both the Immediate and the Delayed test intervals, the typical contexts led to more for both the more- and less-skilled comprehenders experienced. Indeed, as Figure 10 also illustrates, the less-skilled comprehenders benefited more from the typical contexts than the more-skilled comprehenders. These data do not support the hypothesis that less-skilled comprehenders are characterized by less-efficient enhancement mechanisms. Neither do these data support the counter-explanation that less-skilled comprehenders have difficulty rejecting inappropriate information because they less fully appreciate what is contextually appropriate.

FIGURE 10



D. RESULTS OF RESEARCH CONDUCTED UNDER AFOSR-91-0323

In the research we conducted while supported by AFOSR-91-0323, we were interested in further investigating the mechanism of suppression. We asked two important questions: First, is suppression under comprehenders' strategic control? Second, what is the neural basis of suppression?

Is suppression under comprehenders' strategic control?

Our conception of suppression derives from our Structure Building Framework (Gernsbacher, 1990; 1991). According to the Structure Building Framework, memory nodes (the building blocks of mental structures) are automatically activated by incoming stimuli. Once activated, memory nodes transmit processing signals: They send signals to suppress other memory nodes when the information represented by those other nodes is less relevant to the structure being developed. And they send signals to enhance other memory nodes when the information represented by those other nodes is more relevant.

This simple conception suggests that suppression and enhancement operate relatively automatically. According to this conception, suppression and enhancement signals are obligatorily sent, based on some criterion, for instance, a similarity criterion: The less similar the incoming information is with the previous information, the more likely it is to be suppressed; the more similar the incoming information is with the previous information, the more likely it is to be enhanced.

The literature on attention differentiates between this type of passive, mental activity and cognitive processes that are controlled (Keele & Neill, 1978; Posner & Snyder, 1975). Is the mechanism of suppression strategically controlled? The answer to this question is important, for both theoretical and applied reasons. If more-skilled comprehenders' greater ability to suppress irrelevant information is a product of their greater control, perhaps this greater control can be taught. But first we needed to discover whether the mechanism of suppression that we have observed in our previous research — the mechanism of suppression that differentiates more- versus less-skilled comprehenders — is under comprehenders' strategic control.

Automatic versus strategic mechanisms can be differentiated in the laboratory by manipulating the proportion of different types of trials in an experiment. The logic of a proportion manipulation is this: If a certain type of experimental trial occurs with only a low probability, subjects are unlikely to adopt a strategy for that type of trial. But if a certain type of trial occurs frequently, subjects are likely to adopt a strategy for successfully doing that type of trial — if the cognitive mechanism tapped by that type of trial is under the subjects' strategic control.

For instance, consider the following experimental task: Subjects see pairs of letter strings, appearing side by side (e.g., *DORTZ BLAUGH).* The subjects' task is to decide whether each member of the pair is a word. On some trials, both members are words, and on some of the trials in which both members are words, the two words are semantically related, for instance, *BREAD BUTTER*. A classic finding is that the second letter string is recognized faster when it appears in a pair of related words; for instance, *BUTTER* is recognized faster when it is appears in the related word pair *BREAD BUTTER* than when it appears in the unrelated word pair *NURSE BUTTER* (Meyer & Schvaneveldt, 1971).

Now consider the following manipulation: In one condition, only 1/8 of the word trials are related *(BREAD BUTTER)*, and the majority (7/8) are unrelated *(NURSE BUTTER);* in another condition 1/2 are related, and 1/2 are unrelated; and in a third condition, the majority (7/8) of the word trials are related, and only 1/8 are unrelated. With this manipulation, subjects recognize the second word of the pair more rapidly if the pair is related (just as other experiments have shown). But the advantage is a function of the proportion of trials in which the words are related. When only 1/8 of the word trials are related, the advantage is smallest; when 7/8 of the word trials are related, the advantage is largest. Presumably, the high probability of related trials encourages subjects to adopt a strategy for capitalizing on the words' relations (Tweedy, Lapinsky, & Schvaneveldt, 1977).

Manipulating the proportion of various types of trials has similar effects on other strategies that subjects can adopt. For instance, in a letter matching task, subjects are shown pairs of letters, and they decide rapidly whether the members of the pair match (either physically, e.g., *A* and *A*, or in name, e.g., *a* and *A)*. In Posner and Snyder's (1975) experiment, the letter pairs were preceded by three types of cues: an informative cue, which was one of the letters of the pair (e.g., the cue was *A*, and the pair was *AA)*, a neutral cue (a plus sign), or an uninformative cue, which was a different letter than either member of the pair (e.g., the cue was *B*, and the pair was *AA)*. Posner and Snyder (1975) varied the proportion of trials that the cue was informative. It was informative on 20%, 50%, or 80% of the trials. Subjects were fastest when the cue was informative, and when the informative cue occurred 80% of the time. Presumably with a high probability of informative cues, subjects adopted a strategy for taking advantage of the informative cues.

Subjects do not always adopt a strategy, even when there is a high probability of a particular type of trial. Subjects adopt a strategy *only if they can*. For instance, in an experiment in which subjects have to decide whether each member of a pair of letter strings are words, subjects typically adopt a beneficial strategy when there is a high proportion of related word trials (e.g., *BREAD BUTTER* as described above). However, they adopt a strategy only if they have enough time to process the first word of the pair; without adequate time for processing the first word, a 1/8 vs. 1/2 vs. 7/8 ratio of related to unrelated word pairs has no effect (den Heyer, Briand, & Dannenbring, 1983).

Consider another situation in which subjects cannot employ an adaptive strategy. In an experiment conducted by Simpson and Burgess (1985), subjects first read an ambiguous context word, such as *BANK*. After 750 ms, each context word disappeared, and the subjects saw a test word. The subjects made lexical decisions about each test word. On some trials, the test words were related to the **less frequent** meaning of the ambiguous words. For instance, *RIVER* is related to the less frequent meaning of *BANK*. On other trials, the test words were related to the **more frequent** meaning of the ambiguous context words. For instance, *MONEY* is related to the more frequent meaning of the ambiguous word *BANK*. These relations are illustrated in Table 1.

TABLE 1
Example stimuli from Simpson & Burgess, 1985

CONTEXT WORD	TEST WORDS **RIVER**	 **MONEY**
BANK	**Related** to LESS Frequent Meaning	**Related** to MORE Frequent Meaning
RIDDLE	**Unrelated** to Either Meaning	**Unrelated** to Either Meaning

Simpson and Burgess (1985) measured how rapidly subje~ts recognized the test words *(RIVER* or *MONEY)* when the context words were ambiguou *(BANK)* versus unambiguous (e.g., *RIDDLE)*, as illustrated in Table 1. This comparison showed how activated the less- versus more-frequent meanings of the ambiguous words were. Simpson and Burgess (1985) also manipulated the proportion of trials in which the test words were related to the more-versus less-frequent meanings of the ambiguous words. In one condition, the target words were related to the more-frequent meanings on 80% of the trials, and the less-frequent meanings on only 20% of the trials; in another condition, the target words were related to the more- versus less-frequent meanings on an equal number of the trials (50%); and in a third condition, the target words were related to the more-frequent meanings on only 20% of the trials, but they were related to the less-frequent meanings on 80% of the trials.

Simpson and Burgess (1985) found that (at their 750 ms test point), the more-frequent meanings were more highly activated than the less-frequent meanings. And this was the case regardless of the probability manipulation. That is, even when the target words were considerably more likely to be related to the less-frequent meanings, the less-frequent meanings were <u>not</u> more activated. In fact, in a fourth condition, subjects were informed that many of the context words would be ambiguous and that 80% of the target words would be related to the less-frequent meaning of those ambiguous words. But even for those subjects, the less-frequent meanings were still less activated than the more-frequent meanings. These data suggest that subjects cannot adopt a strategy to activate less-frequent meanings of ambiguous words more strongly than less-frequent meanings are perhaps automatically activated. In other words, activating less-frequent meanings is not under comprehenders' strategic control.

In the first series of experiments that we conducted while supported by AFOSR-91-0323, we used a proportion manipulation to investigate whether the suppression mechanism that we identified in our previous research is under comprehenders' strategic control. In the research we conducted while supported by AFOSR 89-3906, we found that suppression is required for selecting against the inappropriate meanings of ambiguous words (e.g., the playing card meaning of *spade* when they read *He dug with the spade);* suppression is also required for selecting against the incorrect forms of homophones (e.g., the concept of *patients* when they read *He had a lot of patience)*; and suppression is required to ignore the typical-but-absent members of scenic arrays (e.g., a *tractor* in an array of objects typically found in a farm scene). In the first three experiments we conducted while supported by AFOSR-91-0323, we investigated whether the mechanism that enables comprehenders to suppress such inappropriate or irrelevant information is under comprehenders' control.

Experiment 1: Is the mechanism that enables comprehenders to suppress the contextually-inappropriate meanings of ambiguous words under their strategic control?

In Gernsbacher et al. (1990; Experiment 4), subjects read short sentences; after each sentence, they saw a test word. Their task was to verify whether the test word fit the meaning of the sentence they just read. On 80 trials, the test word did indeed fit the sentence, but we were more interested in the 80 trials in which the test word did **not** fit the sentence.

On 40 of those trials, the last word of the sentence was an ambiguous word, for example,

(13) He dug with the **spade**.

The test word on these trials was a meaning of the ambiguous word that was inappropriate to the context, for example, *ACE*. We measured how long subjects took to reject a test word like *ACE* after reading a sentence like (13). And we compared that latency with how long subjects took to reject *ACE* after reading the same sentence but with the last word replaced by a unambiguous word, for example,

(14) He dug with the **shovel**.

This comparison showed us how activated the inappropriate meaning of the ambiguous word was; the more time subjects took to reject *ACE* after the *spade*- versus the *shovel*-sentence, the more activated the inappropriate meaning must have been.

We found that immediately (100 ms) after subjects read the ambiguous words, the inappropriate meanings were highly activated, regardless of the subjects' comprehension skill. However, after a one-second delay, the more- versus less-skilled comprehenders differed markedly. For the more-skilled comprehenders, the inappropriate meanings were no longer reliably activated, presumably because the more-skilled comprehenders successfully suppressed them. But for the less-skilled comprehenders, the inappropriate meanings were just as activated after the one-second delay as they were immediately. Thus, more-skilled comprehenders are more able to suppress the inappropriate meanings.

In the first experiment we conducted while supported by AFOSR-91-0323, we investigated whether the mechanism that enables comprehenders to suppress inappropriate meanings is under comprehenders' control. In Experiment 1, subjects read short sentences, and after each sentence, they saw a test word. Their task was to verify whether the test word fit the meaning of the sentence they just read. As before, on 80 trials, the test word did indeed fit the meaning of the sentence, but we were more interested in the 80 trials in which the test word did **not** fit the meaning of the sentence. These were our experimental sentences.

We manipulated how many of these 80 experimental sentences had sentence-final words that were ambiguous versus unambiguous, for example, *He dug with the **spade*** versus *He dug with the **shovel***. In the High-Probability condition, 75% of the 80 experimental sentences contained ambiguous sentence-final words, and only 25% of the experimental sentences had unambiguous sentence-final words. In the Low-Probability condition, only 25% of the 80 experimental sentences contained ambiguous sentence-final words, and 75% had unambiguous sentence-final words. The design of this experiment is summarized in Table 2. The High- and Low-Probability conditions were (of necessity) manipulated between subjects.

The test words for all the experimental sentences were related to a meaning of the ambiguous words, but they were related to a meaning that was inappropriate to the context, for example, *ACE*. All the test words were presented 1000 ms after the offset of the sentence-final words. Rejecting a test word like *ACE* following an ambiguous sentence-final word like *spade* requires suppressing the inappropriate meaning. Rejecting *ACE* following an unambiguous sentence-final word like *shovel* does not require this suppression. If the mechanism that enables comprehenders to suppress inappropriate meanings is under comprehenders' control, then our subjects should have been more inclined to suppress the contextually inappropriate meanings in the High-Probability condition than in the Low-Probability condition.

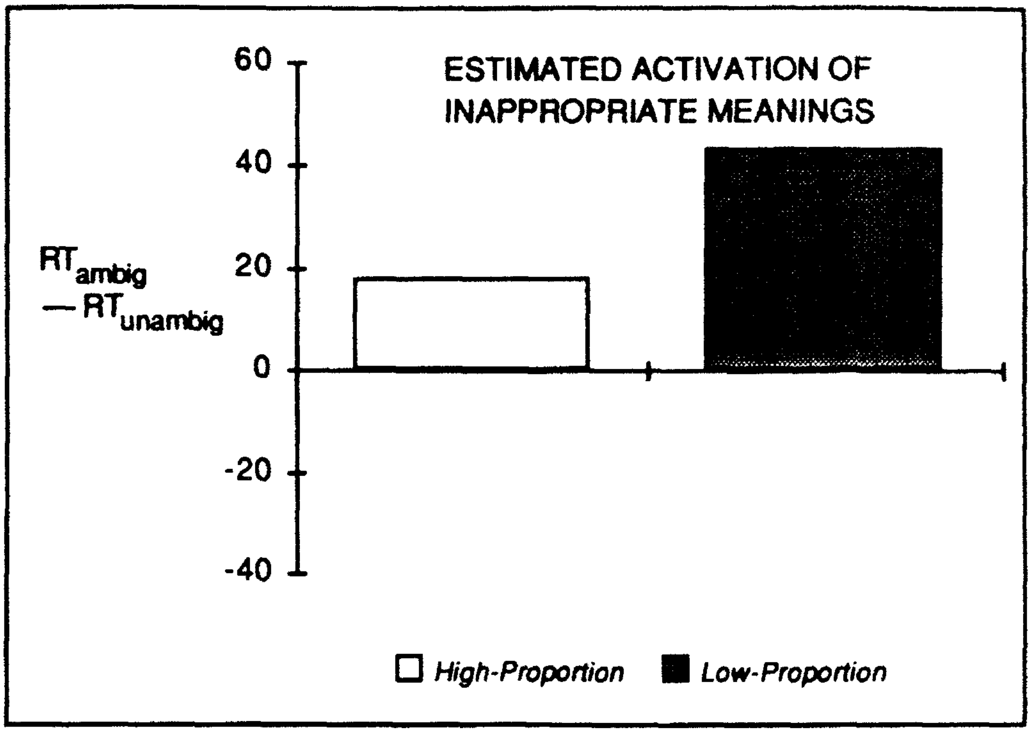
TABLE 2
Design of Experiment 1

	Context Sentence	Test Word	# of Trials	Proportion	Trial Type
Gernsbacher, Varner & Faust (1990)	He dug with the **spade**.	ACE	40	50%	suppression
	He dug with the **shovel**.	ACE	40	50%	no suppression
Low-Probability Condition	He dug with the **spade**.	ACE	20	25%	suppression
	He dug with the **shovel**.	ACE	60	75%	no suppression
High-Probability Condition	He dug with the **spade**.	ACE	60	75%	suppression
	He dug with the **shovel**.	ACE	20	25%	no suppression

Figure 11 (on the next page) displays our 200 subjects' data, presented as estimated activation of the inappropriate meanings. We estimated activation of the inappropriate meanings by subtracting subjects' latencies to reject test words like *ACE* after reading ambiguous words like *spade* from their latencies to reject test words like *ACE* after reading unambiguous words like *shovel*. In Figure 11, the data from the subjects tested in the High-Probability condition are represented by the unfilled bars, and the data from subjects tested in the Low-Probability condition are represented by the unfilled bars.

As Figure 11 illustrates, there was a difference between how activated the inappropriate meanings remained in the Low- versus High-Probability conditions. In the Low-Probability condition, the inappropriate meanings remained more activated. This finding suggests that subjects were more inclined to suppress the contextually inappropriate meanings in the High-Probability condition than they were in the Low-Probability condition. These data support the hypothesis that the mechanism that enables comprehenders to suppress inappropriate meanings is under their control.

FIGURE 11



Experiment 2: Is the mechanism that enables comprehenders to suppress the incorrect form of homophones under their strategic control?

In Gernsbacher and Faust (1991a; Experiment 1), subjects read short sentences, and after each sentence, they saw a test word. Their task was to verify whether the test word fit the meaning of the sentence they just read. On 80 trials, the test word did indeed fit the sentence's meaning, but we were more interested in the 80 trials in which the test word did **not** fit the sentence's meaning.

On 40 of those trials, the last word of the sentence was one form of a homophone, for example,

(15) He had lots of **patients**.

The test word on these trials was related to the homophone's other form, for example, *CALM*. We measured how long subjects took to reject a test word like *CALM* after reading a sentence like (15). And we compared that latency with how long subjects took to reject *CALM* after reading the same sentence but with the last word replaced by a nonhomophone, for example,

(16) He had lots of **students**.

This comparison showed us how activated the incorrect form of the homophone was; the more time subjects took to reject *CALM* after reading the *patients*- versus *students*--sentence, the more activated the incorrect form of the homophone must have been.

We found that immediately (100 ms) after subjects read the sentence-final homophones, the incorrect forms were highly activated, regardless of the subjects' comprehension skill. However, after a one-second delay, the more- versus less-skilled comprehenders differed markedly. For the more-skilled comprehenders, the incorrect forms were no longer reliably activated, presumably because the more-skilled comprehenders successfully suppressed them. But for the less-skilled comprehenders, the incorrect forms were just as activated after the one-second delay as they were immediately. Thus, more-skilled comprehenders are more able to suppress the inappropriate meanings.

In the second experiment we conducted while supported by AFOSR-91-0323, we investigated whether the mechanism that enables comprehenders to suppress incorrect forms of homophones is under comprehenders' control. In Experiment 2, subjects read short sentences, and after each sentence, they saw a test word. Their task was to verify whether the test word fit the meaning of the sentence they just read. As before, on 80 trials, the test word did indeed fit the meaning of the sentence, but we were more interested in the 80 trials in which the test word did **not** fit the meaning of the sentence. These were our experimental sentences.

We manipulated how many of these 80 experimental sentences had sentence-final words that were homophones versus nonhomophones, for example, *He had lots of **patients*** versus *He had lots of **students***. In the High-Probability condition, 75% of the 80 experimental sentences contained homophonic sentence-final words, and only 25% of the experimental sentences had nonhomophonic sentence-final words. In the Low-Probability condition, only 25% of the 80 experimental sentences contained homophonic sentence-final words, and 75% had nonhomophonic sentence-final words. The design of this experiment is summarized in Table 3.

The test words for all the experimental sentences were related to a meaning of the homophone's other form, for example, *CALM*. All the test words were presented 1000 ms after the offset of the sentence-final words. Rejecting a test word like *CALM* following a homophonic sentence-final word like *patience* requires suppressing the incorrect form. Rejecting *CALM* following a nonhomophonic sentence-final word like *students* does not require this suppression. If the mechanism that enables comprehenders to suppress incorrect forms of homophones is under comprehenders' control, then our subjects should have been more inclined to suppress the incorrect forms in the High-Probability condition than in the Low-Probability condition.

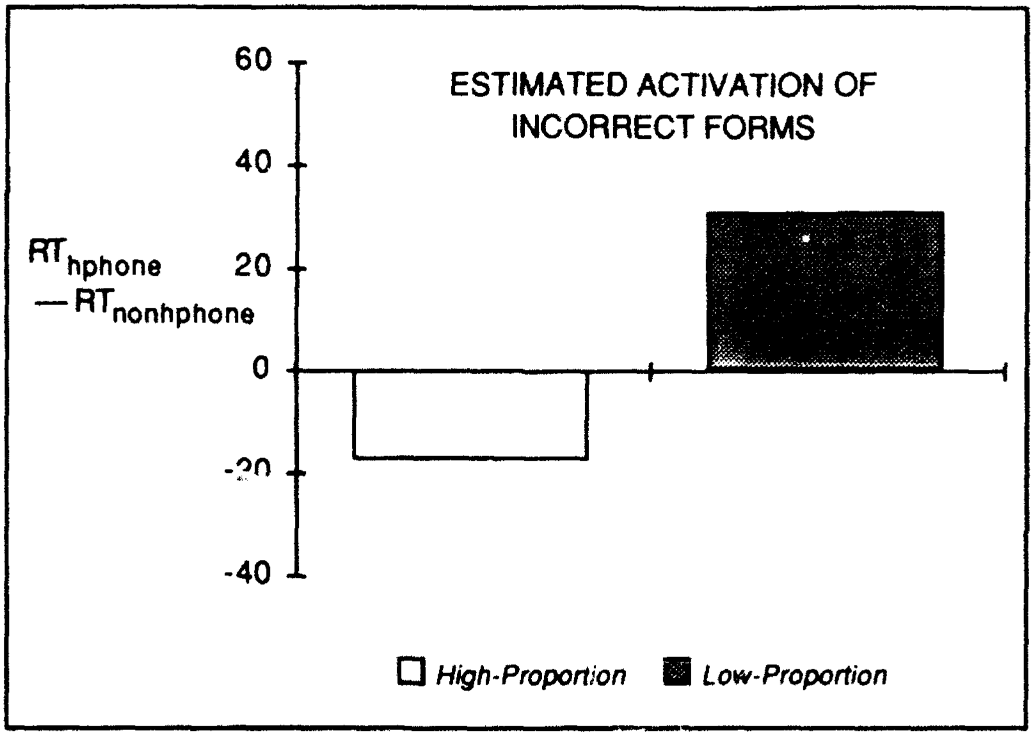
TABLE 3
Design of Experiment 2

	Context Sentence	Test Word	# of Trials	Proportion	Trial Type
Gernsbacher & Faust (1991a)					
	He had lots of **patients.**	CALM	40	50%	suppression
	He had lots of **students.**	CALM	40	50%	no suppression
Low-Probability Condition					
	He had lots of **patients.**	CALM	20	25%	suppression
	He had lots of **students.**	CALM	60	75%	no suppression
High-Probability Condition					
	He had lots of **patients.**	CALM	60	75%	suppression
	He had lots of **students.**	CALM	20	25%	no suppression

Figure 12 displays our 200 subjects' data, presented as estimated activation of the homophones' incorrect forms. We estimated activation of the homophones' incorrect forms by subtracting subjects' latencies to reject test words like *CALM* after reading nonhomophones like *students* from their latencies to reject test words like *CALM* after reading homophones like *patients*. In Figure 12, the data from the subjects tested in the High-Probability condition are represented by the unfilled bars, and the data from subjects tested in the Low-Probability condition are represented by the unfilled bars.

As Figure 12 illustrates, there was a difference between how activated the incorrect forms remained in the Low- versus High-Probability conditions. In the Low-Probability condition, the incorrect forms remained more activated. This finding suggests that subjects were more inclined to suppress the homophones' incorrect forms in the High-Probability condition than they were in the Low-Probability condition. These data support the hypothesis that the mechanism that enables comprehenders to suppress the incorrect forms of homophones is under their control.

FIGURE 12



Experiment 3: Is the mechanism that enables comprehenders to suppress typical-but-absent objects in scenic arrays under comprehenders' strategic control?

In Gernsbacher and Faust (1991a; Experiment 2), subjects viewed arrays of objects that were typical of a particular scene, such as objects from a farm scene. After viewing each array, subjects saw the name of a test object. Their task was to verify whether the named test object had been present in the array they just viewed. On 80 trials, the test object had been present, but in 80 it had not. In this experiment, we were interested in the trials in which the test object had **not** been present.

On half of those trials, the objects in the array were typical of a particular scene, for instance, objects that typically occur in a farm scene. On these trials, the test object was an object that also typically occurs in this type scene, but it had not been present in the scenic array that the subjects just viewed. We compared how long subjects took to reject *TRACTOR* after viewing the farm array with how long they took to reject *TRACTOR* after viewing another scenic array, for instance, objects belonging to a kitchen scene. This comparison showed us how activated the typical-but-absent object was: The longer subjects took to reject *TRACTOR* after viewing the typical *(farm)* array versus the atypical *(kitchen)* array, the more activated the typical-but-absent object must have been.

We found that immediately (50 ms) after subjects viewed the arrays, the typical-but-absent objects were highly activated, regardless of the subjects' comprehension skill. However, after a one-second delay, the more- versus less-skilled comprehenders differed markedly. For the more-skilled comprehenders, the typical-but-absent objects were no longer reliably activated, presumably because they were successfully suppressed. But for the less-skilled comprehenders, the typical-but-absent objects were just as activated after the one-second delay as they were immediately. Thus, more-skilled comprehenders are more able to suppress typical-but-absent objects.

In the third experiment that we conducted while supported by AFOSR-91-0323, we investigated whether the mechanism that enables comprehenders to suppress typical-but-absent objects is under comprehenders' control. In Experiment 3, subjects viewed arrays of objects that were typical of a particular scene, such as objects from a farm scene. After viewing each array, subjects indicated whether a test object was present. On 80 trials, the test object was present, but on 80 trials it was not. We were interested in those 80 trials in which the test object was **absent**. These were our experimental arrays.

We manipulated how many of these 80 experimental arrays were typical versus atypical of the (absent) test object. In the High-Probability condition, 75% of the 80 experimental arrays were typical, and 25% were atypical. In the Low-Probability condition, only 25% of the 80 experimental arrays were typical, and 75% were atypical. The design of this experiment is summarized in Table 4. The High- and Low-Probability conditions were manipulated between subjects.

TABLE 4
Design of Experiment 3

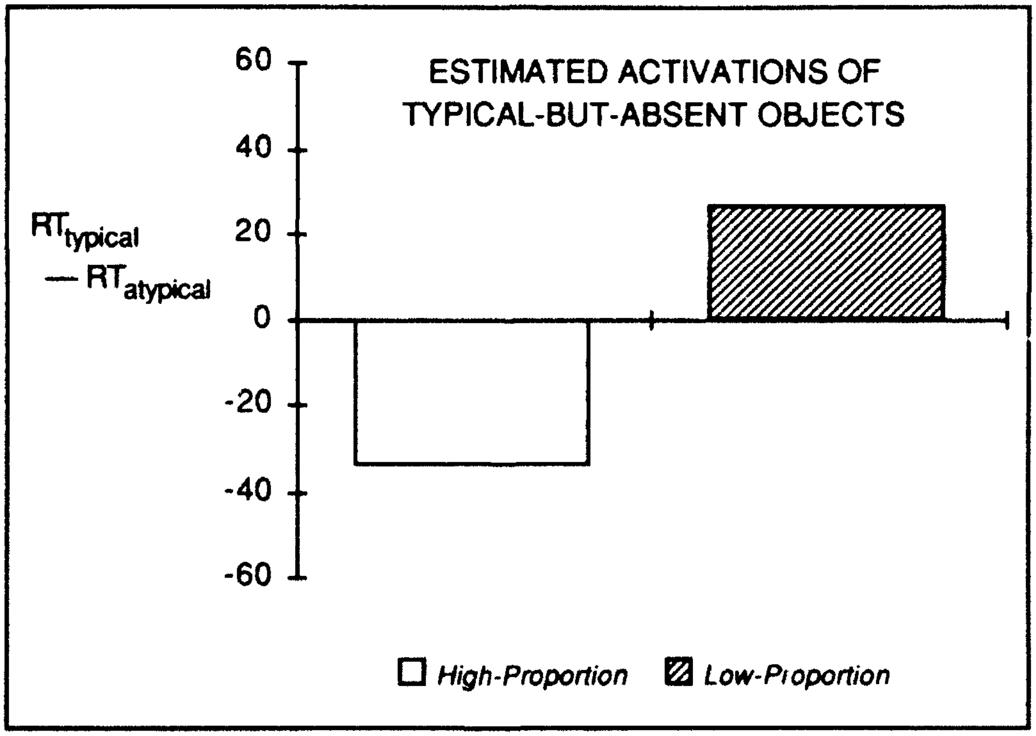
	Array	Test Object	# of Trials	Proportion	Trial Type
Gernsbacher & Faust (1991a)					
	farm items (typical)	TRACTOR	40	50%	suppression
	kitchen items (atypical)	TRACTOR	40	50%	no suppression
Low-Probability Condition					
	farm items (typical)	TRACTOR	20	25%	suppression
	kitchen items (atypical)	TRACTOR	60	75%	no suppression
High-Probability Condition					
	farm items (typical)	TRACTOR	60	75%	suppression
	kitchen items (atypical)	TRACTOR	20	25%	no suppression

The test object on all the experimental trials was an object not present in the array. Rejecting a test object like *TRACTOR* following an array of farm objects requires suppressing the typical-but-absent object. Rejecting *TRACTOR* following an array of kitchen objects does not require this suppression. If the mechanism that enables comprehenders to suppress typical-but-absent objects is under comprehenders' control, then subjects should have been more inclined to suppress the typical-but-absent objects in the High-Probability condition than in the Low-Probability condition.

Figure 13 displays our 100 subjects' data, presented as estimated activation of the typical-but-absent objects. We estimated activation of the typical-but-absent objects by subtracting subjects' latencies to reject test objects like *TRACTOR* after viewing atypical *(kitchen)* arrays from their latencies to reject test objects like *ACE* after viewing atypical *(kitchen)* arrays. In Figure 13, the data from the subjects tested in the High-Probability condition are represented by the unfilled bars, and the data from subjects tested in the Low-Probability condition are represented by the unfilled bars.

As Figure 13 illustrates, there was a difference between how activated the typical-but-absent objects remained in the Low- versus High-Probability conditions. In the Low-Probability condition, the typical-but-absent objects remained more activated. This finding suggests that subjects were more inclined to suppress the typical-but-absent objects in the High-Probability condition than they were in the Low-Probability condition. These data support the hypothesis that the mechanism that enables comprehenders to suppress typical-but-absent objects is under their control.

FIGURE 13



What is the neural basis of the mechanism of suppression?

Many contemporary cognitive psychologists want to link cognitive mechanisms and processes with neural functions and locations (Posner, Peterson, Fox, & Raichle, 1987; Posner, Sandson, Dhwan, & Shulman, 1989). Cognitive psychologists (and cognitive neuropsychologists) are motivated to link cognitive mechanisms with underlying neural functions and locations to validate their proposed mechanisms, to better understand neural architecture, and to aid clinical diagnosis and treatment of neural damage.

In the second set of experiments that we conducted while supported by AFOSR-91-0323, we adopted this cognitive neuropsychological approach. In particular, we conducted two experiments that allowed us to begin to localize the general suppression mechanism we identified in our previous work. Our general question was whether the mechanism of suppression is tied to the action of one cerebral hemisphere or whether the mechanism of suppression is employed by both hemispheres.

Perhaps one hemisphere specializes in suppression, in the same way that some cognitive tasks are better performed by one cerebral hemisphere. For instance, many linguistic tasks are assumed to be better performed in the left cerebral hemisphere than the right cerebral hemisphere. Or perhaps each hemisphere possesses a suppression mechanism. This hypothesis is similar to the proposal that one hemisphere often "asserts control" during a cognitive task. Which hemisphere asserts control usually depends on which hemisphere is most effective at performing the task (Hellige, Taylor, & Eng, 1989; Levy & Trevarthen, 1976). For instance, perhaps during linguistic tasks, suppression signals are primarily sent by the left hemisphere, because it is the more active hemisphere. Or perhaps the suppression mechanism is not localized in either hemisphere. The experiments we propose to conduct at AFHRL will help us discriminate among these hypotheses.

Our starting point for these two experiments was a study by Burgess and Simpson (1988), which used a split-visual field methodology. The logic of a split-visual field experiment draws on the following neuroanatomy: The connections from the photoreceptors in the two retinae (of the two eyes) are split at the vertical meridian. The connections from the right half of the visual field go first to the left hemisphere of the brain, and the connections from the left half of the visual field go first to the right hemisphere. In typical (day-to-day) cognitive activity, these advantages matter little because our eyes are constantly moving, and information stimulates both visual fields. Furthermore, even if there is a slight advantage for the hemisphere that receives the information first, the information is quickly integrated across the hemispheres (because of the rich connections between them provided by the corpus callosum).

However, in the laboratory, experimenters try to capitalize on these slight advantages by presenting information to one visual field only and presenting the information very briefly — before subjects can move their eyes (Hines, 1978; Hines, Sawyer, Dura, Gilchrist, & Czerwinski, 1984). In this way, experimenters can stimulate one hemisphere before the other, and experimenters can investigate whether the hemispheres differ in the way they enable certain cognitive processes and mechanisms.

As we mentioned above, Burgess and Simpson (1988) used a split-field methodology. First, subjects read an ambiguous context word, such as *BANK*, which was presented quickly (for 35 ms) in the center of the computer screen. Following each context word, a test word was presented briefly (for 185 ms) to either the right or left visual field (and, therefore, either the left or the right hemisphere was the first to process the test word).

The subjects' task was to decide rapidly whether each test word was an English word. As in the experiment by Simpson and Burgess and Simpson (1985), the test words were related to either the less- or more- frequent meaning of the ambiguous context words, as illustrated in Table 1. Burgess and Simpson (1988) measured how rapidly subjects could decide that the test words *(RIVER* or *MONEY)* were English words when the context words were the ambiguous words *(BANK)*. And they compared those decision times with how quickly subjects could decide that the same words were English words when they were presented after unrelated ambiguous words (e.g., *RIDDLE)*, as illustrated in Table 1. This comparison showed Burgess and Simpson (1988) how activated the less- and more-frequent meanings of the ambiguous words were; the faster subjects recognized the test words when they were presented after the ambiguous context words as opposed to the unrelated context words, the more activated the less and more-frequent meanings must have been.

The test words appeared either immediately after the context words disappeared (e.g., immediately after either *BANK* or *RIDDLE* disappeared). Or the test words appeared 715 ms after the context words disappeared. Burgess and Simpson's (1988) results are shown in Figures 14 and 15, expressed in ms of estimated activation. We estimated activation by subtracting subjects' decision times to test words like *RIVER* or *MONEY* following context words like *BANK* from their decision times to *RIVER* or *MONEY* following context words like *RIDDLE*. The less-frequent meanings are represented by cross-hatched lines, and the more-frequent meanings are represented by unfilled bars.

FIGURE 14

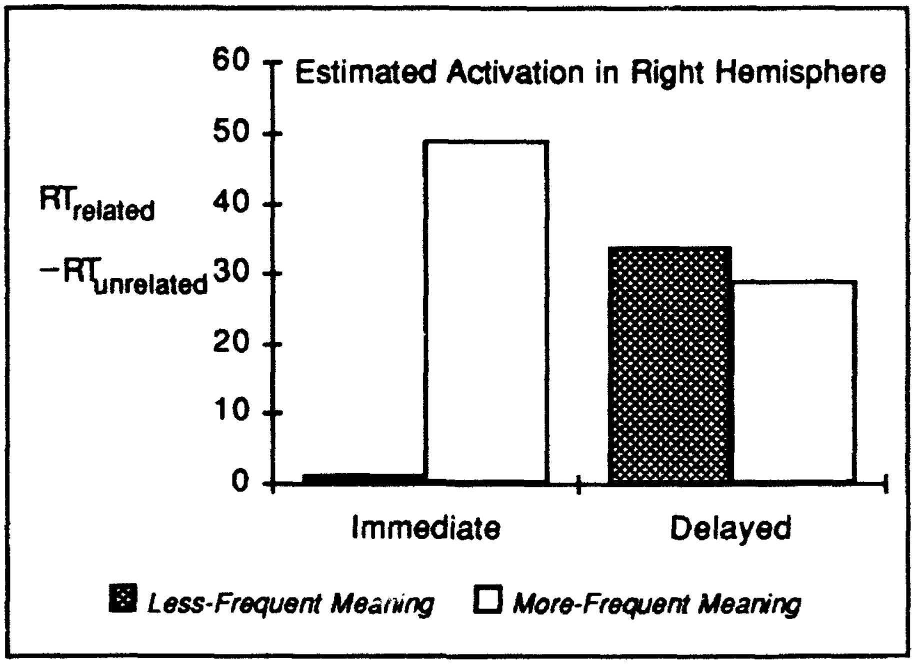


FIGURE 15

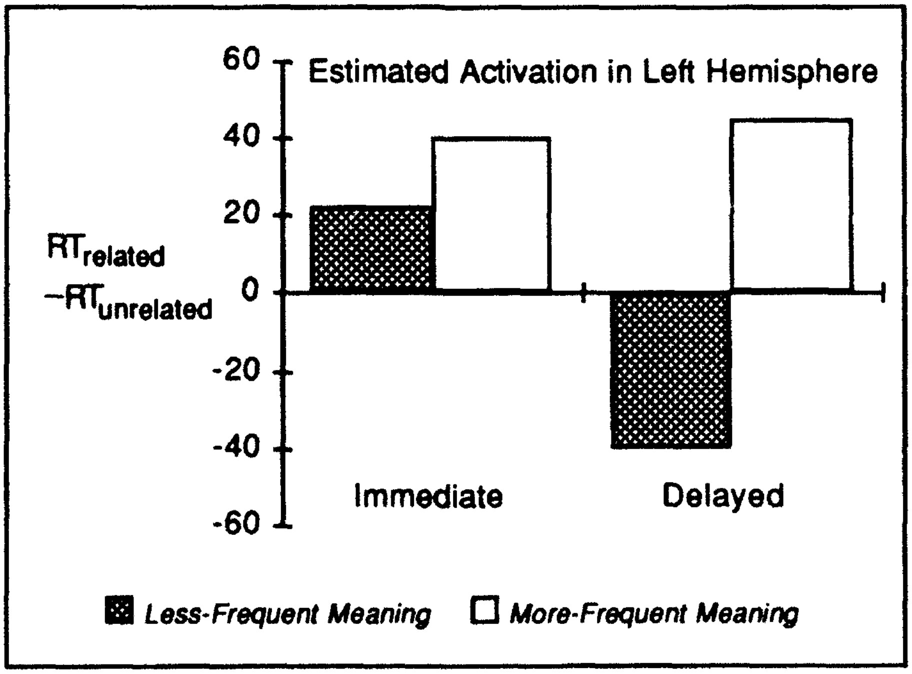


Figure 14 presents the estimated activation of the less- versus more-frequent meanings when the test words were presented in the left visual field and, therefore, were processed first by the right cerebral hemisphere. As Figure 14 illustrates, at the immediate interval, only the more-frequent meanings were activated (in the right hemisphere). But after the delay, both the less- and the more-frequent meanings were activated in the right hemisphere.

Figure 15 presents the estimated activation of the less- versus more-frequent meanings when the test words were presented in the right visual field and, therefore, were processed first by the left cerebral hemisphere. As Figure 15 illustrates, at the immediate interval, both the less- and the more-frequent meanings were activated (in the left hemisphere). But after the delay, only the more-frequent meanings were activated; the less-frequent meanings were considerably less activated.

From these data, Burgess and Simpson (1988) concluded that the right and left hemispheres play different roles during the comprehension of ambiguous words. They suggested that the right hemisphere processes the meanings sequentially, with more frequent meanings being processed before the less frequent meanings. The right hemisphere allows multiple meanings to remain active, even after the delay. But Burgess and Simpson (1988) suggested that, in contrast to the right hemisphere, the left hemisphere quickly disambiguates words on the basis of their frequency of meaning, and Burgess and Simpson (1988) suggested that the left hemisphere does this by suppressing the activation of the less-frequent meaning. Is the mechanism proposed by Burgess and Simpson (1988) to deactivate the less-frequent meanings of ambiguous words the same mechanism of suppression that we identified in our previous research?

Experiment 4: Is one hemisphere specialized for suppressing contextually-inappropriate meanings of ambiguous words?

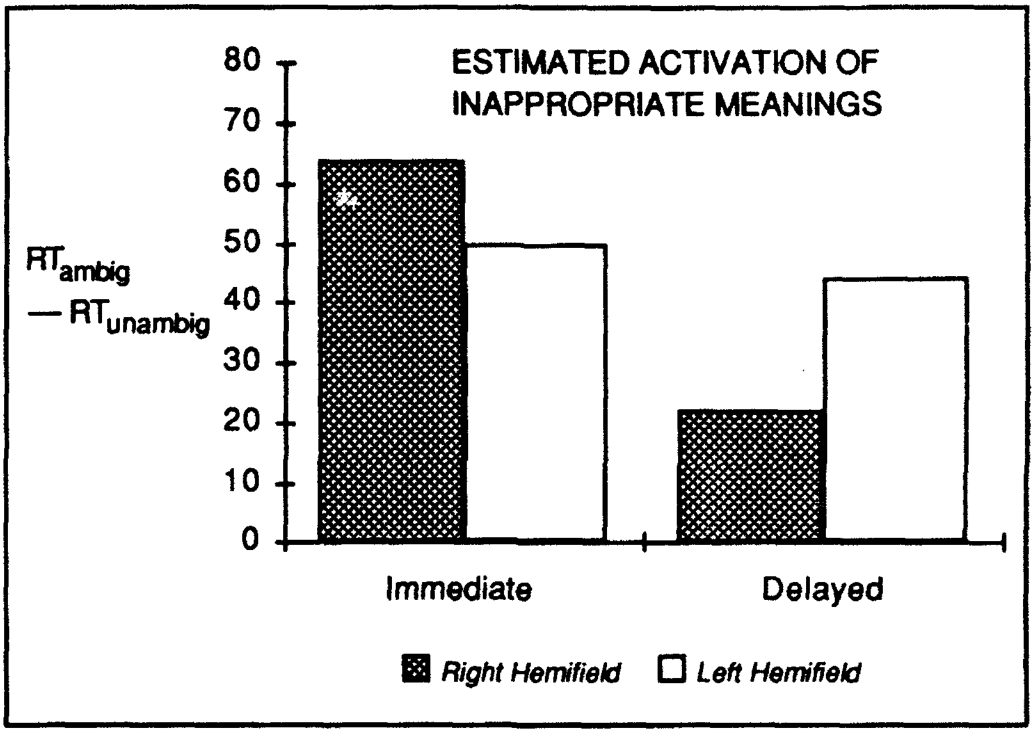
Burgess and Simpson (1988) suggested that the left-hemisphere was specialized for suppressing the less-frequent meanings of ambiguous words. *Is the left hemisphere also specialized for suppressing the contextually inappropriate meanings of ambiguous words?* In the fourth experiment that we conducted while supported by AFOSR-91-0323, we used a split-visual field methodology to answer this question. Our subjects read short sentences. Each sentence was shown one word at a time, with each successive word appearing in the center of a screen. All words in the sentence were presented at a comfortable reading rate, as in our previous research (Gernsbacher et al., 1990). Following the final word of each sentence, a test word was presented. The test word appeared in either the left- or right-visual field. On 80 trials, the test word did indeed fit the sentence, but we were more interested in the 80 trials in which the test word did **not** fit the sentence.

On half of those trials, the last word of the sentence was an ambiguous word, for example, *He dug with the* ***spade***, or the last word of the sentence was an unambiguous word, for example, *He dug with the* ***shovel***. The test words on these trials was related to a meaning of the ambiguous word that was inappropriate to the context, for example, *ACE*. We measured how long subjects took to reject a test word like *ACE* after reading the *spade*- versus the *shovel*-sentence. The less time subjects take to reject *ACE* after reading the *spade*- versus the *shovel*-sentence, the more successfully they can suppress the inappropriate meaning. We compared the subjects' performance when the test words were presented in the right- versus left-visual field.

Subjects sat approximately 0.5 meters from the computer screen. The test words appeared vertically 2.5 degrees of visual angle to the right or left of the fixation cue (a plus sign that appeared in the center of the screen before each trial). The test words appeared at one of two test intervals: either 100 ms or 1000 ms after the sentence-final word (the ambiguous or unambiguous word) disappeared. Thus, each trial proceeded in the following way: A plus sign appeared for 750 ms in the center of the screen. Then, each word of the sentence appeared, also in the center of the screen. Then, the test word appeared in either the left or right visual field, for a duration of 250 ms. As soon as the test word appeared, subjects could initiate their response; however, we ignored from our analyses any reaction times that were less than 250 ms because those latencies were too short to aptly capture subjects' decisions.

Figure 16 displays our 300 subjects' data. We estimated activation by subtracting subjects' latencies to reject test words like *ACE* after reading ambiguous words like *spade* from their latencies to reject test words like *ACE* after reading unambiguous words like *shovel*. The data from trials in which the test words were presented to the right hemifield (and therefore the test words were first processed by the left hemisphere) are represented by hashed lines, and the data from trials in which the test words were presented to the left hemifield (and therefore the test words were first processed by the right hemisphere) are represented by the unfilled bars.

FIGURE 16



First, examine what happened at the Immediate test interval. As Figure 16 illustrates, immediately after subjects read the ambiguous words, the inappropriate meanings were highly activated -- regardless of the hemifield in which the words were presented. Now, examine what happened after the Delayed interval. As Figure 16 illustrates, when the test words were presented 1000 ms after the subjects read the ambiguous words, the inappropriate meanings were reliably less activated -- when the test words had been presented to the right hemifield (and had been processed first by the left hemisphere). These results replicate those of Burgess and Simpson (1988) and suggest that the left hemisphere is specialized for suppressing the meanings of ambiguous words.

Experiment 5: Is one hemisphere specialized for suppressing the incorrect forms of homophones?

There is some evidence that the left hemisphere is specialized for processing phonological information. For instance, when subjects judge whether two letter strings sound alike (e.g., *BORE - BOAR*), stimuli presented to the right visual field (and, therefore, processed first by the left hemisphere) are responded to more rapidly (Rodel, Dudley, & Bourdeau, 1983). Similarly, consonant-vowel-consonant trigrams (e.g., K-I-P) are more likely to be processed as a phonetic (sound) unit when presented to the right visual field (and, therefore, processed first by the left hemisphere); the same consonant-vowel-consonant trigrams are more likely to be processed as an orthographic (written) letter string when presented to the left visual field (Hellige et al., 1989).

In our previous research, we found that comprehending homophones (e.g., *rose)* often requires suppressing the alternate forms (e.g., *rows).* Given that the left hemisphere is specialized for processing phonological information, we wondered whether the mechanism that suppresses the incorrect forms of homophones during sentence comprehension is localized in the left hemisphere.

Each sentence was shown one word at a time, with each successive word appearing in the center of a screen. Following the final word of each sentence, a test word was presented. The test word appeared in either the left- or right-visual field. The subjects' task was to verify whether the test word fit the meaning of the sentence they just read. On 80 trials, the test word did indeed fit the meaning of the sentence, but we were more interested in the 80 trials in which the test word did **not** fit the meaning of the sentence.

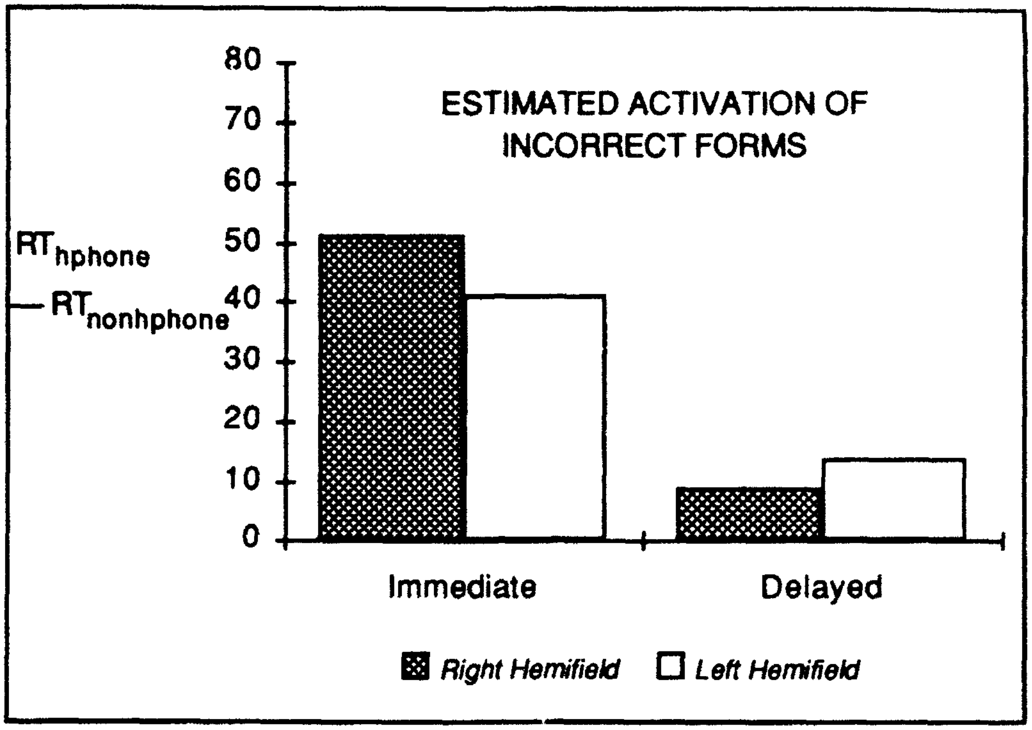
On half of those trials, the last word of the sentence was a homophone, for example, *He had lots of* ***patients***, or the last word of the sentence was a nonhomophone, for example, *He had lots of* ***students***. The test word on these trials was a word related to the other form of the homophone, for example, *CALM*. We measured how long subjects took to reject a test word like *CALM* after reading the *patients*- versus the *student*-sentence. The less time subjects take to reject *CALM* after reading the *patients*- versus the *students*-sentence, the more successfully they can suppress the inappropriate meaning. We compared the subjects' performance when the test words were presented in the right- versus left-visual field.

Subjects sat approximately 0.5 meters from the computer screen. The test words appeared vertically 2.5 degrees of visual angle to the right or left of the fixation cue (a plus sign that appeared in the center of the screen before each trial). The test words appeared at one of two test intervals: either 100 ms or 1000 ms after the sentence-final word (the homophone or nonhomophone) disappeared. Thus, each trial proceeded in the following way: A plus sign appeared for 750 ms in the center of the screen. Then, each word of the sentence appeared, also in the center of the screen. Then, the test word appeared in either the left or right visual field, for a duration of 250 ms. As soon as the test word appeared, subjects could initiate their response; however, we ignored from our analyses any reaction times that were less than 250 ms because those latencies were too short to aptly capture subjects' decisions.

Figure 17 displays our 250 subjects' data. We estimated activation by subtracting subjects' latencies to reject test words like *CALM* after reading homophones like *patients* from their latencies to reject test words like *CALM* after reading nonhomophones like *students*. The data from trials in which the test words were presented to the right hemifield (and therefore the test words were first processed by the left hemisphere) are represented by hashed lines, and the data from trials in which the test words were presented to the left hemifield (and therefore the test words were first processed by the right hemisphere) are represented by the unfilled bars.

First, examine what happened at the Immediate test interval. As Figure 17 illustrates, immediately after subjects read the homophones, the incorrect forms were highly activated -- regardless of the hemifield in which the words were presented. Now, examine what happened after the Delayed interval. As Figure 17 illustrates, when the test words were presented 1000 ms after the subjects read the homophones, the incorrect forms were reliably less activated -- regardless of the hemifield in which the words were presented. These data suggest that both hemispheres play a role in suppressing the incorrect forms of homophones.

FIGURE 17



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APPENDIX
ARTICLES AND CHAPTERS RESULTING FROM AFOSR 89-0306 AND 90-0323

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